International Journal of Basic and Applied Sciences, 14 (1) (2025) 166-180

International Journal of Basic and Applied Sciences

Website: www.sciencepubco.com/index.php/IJBAS
https://doi.org/10.14419/h0y6dw98
Research paper

Exploring governance frameworks and decision processes in blockchain-based decentralized autonomous organizations

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Received: April 2, 2025, Accepted: May 1, 2025, Published: May 5, 2025

Abstract

Decentralized Autonomous Organizations (DAOs), which employ smart contracts and blockchain technology to facilitate decentralized, democratic, and transparent decision-making, are an innovative change in organizational governance. This study examines the basic architecture of DAOs in the larger blockchain ecosystem, emphasizing how smart contracts help automate governance procedures. On-chain and off-chain governance models are the main topics of this thorough analysis of DAO governance systems. Off-chain governance refers to the decision-making process that happens outside the blockchain to increase flexibility and efficiency. In contrast, on-chain governance uses blockchain-based voting to guarantee transparency and immutability. A comparison of these models assesses their benefits, drawbacks, and compromises, especially regarding decentralization, security, and decision-making efficiency. There is also discussion of developments in DAO governance, such as cross-chain interoperability, hybrid models, and AI-assisted decision-making. The results highlight the necessity of a well-rounded governance strategy that incorporates both off-chain flexibility and on-chain security. By providing insights on optimizing decision-making frameworks for decentralized organizations, this research adds to the continuing discussion on DAO governance.

Keywords: *DAO; Blockchain; Smart Contracts; On-Chain Governance; Off-Chain Governance; Quadratic Voting; Reputation Based Systems.*

1. Introduction

Decentralized autonomous organizations are blockchain-based digital organizations that operate independently of a central authority. The laws regulating DAOs are represented in smart contracts, which are contracts that automatically execute themselves and have the contract terms placed directly into lines of code [1], [2]. With this configuration, decentralized autonomous organizations (DAOs) can operate without the conventional organizational framework, which gives them an innovative approach to decisions and regulation. The community determines decision-making in a DAO. It is possible to do this by providing participants with voting power proportional to their contribution to the organization, which is often represented by crypto tokens. Members have the power to vote on proposals and suggest modifications through these tokens, which serve as both a payment and a voting instrument. In this democratic method, individuals are given more authority, and the organization's activities are aligned with the community's wishes.

DAOs are constructed using blockchain technology, delivering both transparency and security. Every activity, decision, and vote is stored on a public ledger. This ensures that all activities are accessible to anybody and can be verified by anyone [3]. Moreover, the blockchain's security characteristics help safeguard DAOs against fraudulent activity and illegal manipulation, making them a trustworthy alternative for managing digital assets. DAOs represent a trend toward more democratic and decentralized organizational structures, marked by their popularity surge. DAOs are a paradigm that turns the traditional business model into a decentralized and democratic organization, as traditional organizations rely on a top-down approach.

DAOs can largely function through smart contracts, automating procedures and decisions without human interaction [4]. The rules that govern the organization are established by these contracts, which also carry out the activities that have been accepted automatically when specific circumstances are satisfied. This automation is especially useful in the Bitcoin industry, which moves quickly and where timely decisions may be critical. Individuals often acquire governance tokens to take part in a DAO. In exchange for these tokens, holders can

vote on ideas and influence the organization's overall direction [5]. A community vote is required for proposals to be approved and put into action inside a DAO. This procedure guarantees that decisions are made by the desire of the members rather than the interests of a small group of influential individuals. Voting processes can vary, with some DAOs using a straightforward majority rule.

In contrast, others may adopt more sophisticated approaches, such as quadratic voting, to balance various stakeholders' impact [5]. It does not matter which approach is taken; the objective is still the same: to establish a decision-making procedure that is both democratic and fair. Because it offers the infrastructure required to build and administer smart contracts efficiently, the Ethereum network has become a popular platform for DAOs.

Members are motivated to contribute to the success of the DAO. This direct engagement gives investors a unique opportunity to influence the future of projects and initiatives they are enthusiastic about [3, 4, 5]. DAOs offer opportunities for community-driven innovation and creativity. By bringing together a varied collection of people from all over the world, DAOs can tap into a wide variety of expertise, views, and experiences. The members of this diverse group work together and exchange their ideas to develop unique solutions and methods, stimulating creativity. Harnessing collective intelligence is a key advantage in today's environment, which places a greater emphasis on innovation and adaptability than ever before.

The global cooperation made possible by DAOs is not limited by geography or culture [6]. Participants from different geographical locations can join and contribute to DAOs, which bring together a wealth of information and skills. Lastly, DAOs create ecosystems where value is distributed among contributors and stakeholders. To align participants' interests with the organization's performance, DAOs distribute rewards and incentives to token holders [6]. When members of this shared value model work together to accomplish shared objectives, it fosters an environment conducive to collaboration and cooperation. Table 1 provides definitions of essential technical terms used throughout the paper.

Table 1: Technical Terms with Explanation

Term	Explanation
DAO	Decentralized Autonomous Organization: an organization operated via smart contracts on a blockchain without centralized control.
Blockchain	A distributed, immutable ledger for recording transactions securely across multiple nodes.
Smart Contracts	Self-executing programs are stored and executed on a blockchain automatically to enforce an agreement's terms and conditions without intermediaries.
On-chain Governance	Decision-making processes and voting are conducted directly on the blockchain, involving stakeholders in protocol-level decisions.
Off-chain Governance	Discussions, debates, and decision-making processes that happen outside the blockchain (e.g., forums, social media, or other communication channels).
Proposals	Suggestions or changes are presented for voting, typically related to governance decisions, funding allocation, or protocol updates.
Tokens	Digital assets or units of value that represent ownership or voting power within a blockchain-based system.
Bitcoin	The first decentralized cryptocurrency that uses blockchain technology for peer-to-peer transactions without a central authority.
Ethereum	A blockchain platform that makes it possible to create smart contracts and decentralized apps.
Voting	An approach to decision-making in which participants voice their preferences to decide on a group action or result.
Token-Based Voting	A voting system where each Participant's voting power is based on how many tokens they own.
Quadratic Voting	A voting method that represents preference intensity by quadratically allocating votes.
Delegated Voting	A governance system where members assign voting power to a delegate who votes for them.
Holographic Consensus	A hybrid governance paradigm that ensures scalability and efficiency in decentralized systems by using off-chain signaling to forecast probable on-chain choices.
Sybil Attacks	A type of attack where a malicious actor creates multiple fake identities to gain disproportionate influence or control over a system, such as voting.

The remainder of the paper is structured as follows. It begins by comparing DAOs and traditional organizational models, then introducing the blockchain ecosystem as a foundational element. An overview of smart contracts and their development life cycle is then presented. A focused introduction to DAOs is provided next. Governance mechanisms are discussed in two parts: on-chain governance, highlighting key opportunities and challenges, and off-chain governance, which explores its unique features and associated issues. The mechanism of DAO governance is outlined, followed by a detailed examination of various voting mechanisms. Challenges related to DAO governance are then addressed. Recent trends and developments in the DAO landscape are reviewed to provide insight into the evolving nature of the field. The paper concludes with a summary of findings and directions for future research.

2. Comparison of traditional organizations and DAO

The fast-changing digital environment is transforming enterprises. Organizational structures with centralized decision-making have long backed both societal and financial sectors. DAOs function without centralized authority using smart contracts and decentralized governance, changing decision-making, control, and reward distribution [5, 6]. DAOs use community engagement, transparent algorithms, and blockchain-driven automation, while traditional enterprises use human-led authority, legal structures, and institutional trust. This change offers openness, flexibility, and inclusion but raises regulation, technical vulnerability, and governance efficiency issues. The key distinctions between DAO and traditional organizations are outlined in Table 2.

Table 2: Traditional Organizations Versus DAO

Parameter	Traditional Organization	Decentralized Autonomous Organization (DAO)
Decision-Making	Managers and top administrators make major decisions.	Decentralized and community-driven via smart contracts and Voting
Organizational Structure	Multi-level and hierarchical management	Flat, democratic, and decentralized, all participants govern equally.
Autonomy	Low to moderate; leadership-driven.	Highly automated by smart contracts.
Openness	Limited membership and participation are restricted internally.	Based on the protocol, anybody may join or contribute.
Ownership	Shareholders, founders, or board members.	Token holders or contributors.
Transparency	Restricted; internal operations are usually confidential.	Every Participant can view transactions and decisions on the blockchain.

Adaptability	Moderate; depends on leadership adaptability	Proposals allow continual evolution, but smart contracts may limit technological modifications.
Incentive Mechanism	Performance-based salaries, incentives, and stock options	Rewards like tokens, staking bonuses, or protocol-based profits
Regulatory Framework	Clear and well-established business law regulations	Still evolving; varies across countries; regulatory gray areas exist
Funding	Conventional methods such as bank loans, venture capital, and earnings	Token sales, initial coin offerings (ICOs), and community grants are ways to raise money.
Trust Model	Based on trust in leadership, brand, and compliance	Based on trust in algorithms, code, and full transparency
Speed of Operations	Potentially quicker at executive levels, but delayed at bureaucratic levels	Depends on community responsiveness; may be slower due to voting processes
Failure Risk	Mismanagement, leadership failure, and fraud	Vulnerabilities in smart contracts, low voter turnout, and governance attacks

3. Blockchain ecosystem

The blockchain is a distributed ledger system that uses a network of computer systems to securely store information in a way that is immutable, accessible, and tamper-proof [7]. A significant proportion of individuals in the system verify each transaction. In the digital currency realm, blockchains are most well-known for their role in maintaining a secure and decentralized record of transactions. Blockchain ensures that all participants have access to the most recent information simultaneously. However, besides their use in cryptocurrencies, they have many other uses. There are several benefits associated with blockchain technology, including reducing costs via increased efficiency and enhancing the monitoring of data transferred throughout a business process. This results in an improvement in trust, safety, and openness among member organizations. The mechanism of processing transactions in blockchain is depicted in Fig. 1.

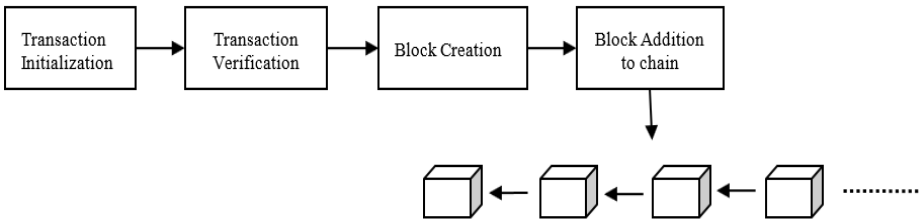

Fig. 1: Blockchain Transaction.

The record of the data that is accessed or edited on a blockchain is placed in a "block" alongside the records of other transactions whenever the data is accessed or amended [8, 9, 10]. Hashes that cannot be altered are used to encrypt stored transactions. New data blocks do not erase older ones; rather, they are "chained" together to enable the monitoring of any changes that may occur. These blocks of encrypted data are "chained" to one another permanently. It creates a flawless audit history that enables insight into previous versions of the blockchain. Consensus mechanisms require most nodes in the network to validate transactions. A new block is added to the chain after consensus is established. The blockchain ledger is then reflected on all nodes.

4. Smart contracts

The foundation of DAOs is smart contracts. They specify the organization's policies and procedures, managing issues from voting procedures and voting rights to financial management and governance enforcement [4]. Because these contracts are implemented on a blockchain, they cannot be modified or altered once they become operational. Additionally, since the smart contract defines the treasury, no one can spend the funds without the group's consent [11]. Thus, a central authority is not necessary for DAOs. Smart contracts can improve DAOs' security, trust, and openness.

By guaranteeing a single source of truth, minimizing human work, and avoiding mistakes, smart contracts offer a safe, automated, and effective means of carrying out agreements [12]. They increase process speed and reduce costs by eliminating the need for intermediaries. They function openly on decentralized networks with a zero-trust framework, which lessens dependency on outside parties. Furthermore, smart contracts include built-in backup, guaranteeing that transactional data is always kept safe and accessible. These characteristics make them a dependable and effective option for various uses, such as financial transactions and DAOs. A smart contract uses blockchain technology to provide efficiency, transparency, and security while acting as a legally enforceable agreement between two parties [13]. It uses straightforward "if/when…then…" phrases to function.

To develop smart contracts, stakeholders involved in the business discuss and document the terms and conditions of the business. The next step in creating a contract is to code it, to check it for vulnerabilities, and then upload it to the blockchain. After going into effect, the contract keeps an eye on operations; when the requirements are met, execution occurs, automating tasks like altering ownership or sending money. Lastly, recording guarantees the transaction is permanently available by logging and verifying it on the blockchain. Figure 2 depicts the smart contract development life cycle.

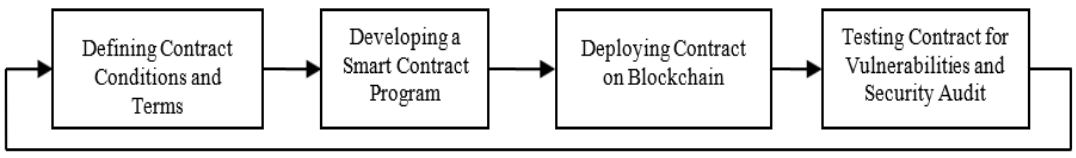

Fig. 2: Smart Contract Development Cycle.

5. Introduction to governance mechanisms in DAO

A governance mechanism is important for DAOs' success, functioning, and existence. Governance in DAO defines rules, voting mechanisms, protocol upgrades, dispute resolution, and decision-making that decide how DAO will operate and change over time [14, 15]. Efficient governance guarantees to the participants, developers, and stakeholders that DAO will operate effectively, maintain security, and adapt to changes over time. Governance also defines how decision-making rights are distributed among stakeholders. An effective governance mechanism protects assets from malicious actors. A well-defined governance mechanism in DAOs helps form rules, regulations, and processes for the functioning of DAOs. Token-based voting is common to DAO governance mechanisms in which members employ governance tokens to submit proposals and vote on DAO operations. It allows all members of DAO to participate in the decision-making process, maintaining the decentralized nature of DAO. However, members of DAOs holding large numbers of tokens can dominate decision-making in DAOs.

Another important feature of DAO governance is its role in maintaining the treasury and incentive structure. The governance mechanism decides how assets are distributed and managed and how members are rewarded for their contributions [16]. However, a poor governance model can lead to misallocation of assets and a power imbalance favoring large token holders. Using impartial and transparent mechanisms such as quadratic voting or reputation-dependent voting can help in fair decisions and avoid power concentrations. The security and safety of DAOs also rely on governance mechanisms. All DAO operations happen through smart contracts. Weaknesses in governance mechanisms can expose smart contracts to different types of vulnerabilities, resulting in loss of funds and reputation. Smart contract auditing can help in preventing various kinds of attacks. In case of attacks, an emergency response mechanism is essential to maintain the security of DAOs. It is also necessary to ensure that DAOs allow protocol upgrades and regulation changes per participants' requirements.

DAO efficacy and sustainability will be determined by its governance. By encouraging openness, fair involvement, and flexibility, robust governance structures guarantee that DAOs stay decentralized while achieving their desired objectives [17]. As their popularity increases, improving governance structures will be essential for DAOs' survival and implications in the larger decentralized ecosystem. There are several forms of DAO governance, and each has advantages and disadvantages of its own. These decentralized networks' reliability, safety, and sustainability depend on efficient governance as blockchain technology develops. The collection of guidelines that determine how votes are made inside a blockchain network is known as blockchain governance. The two main governance models used by DAOs are on-chain and off-chain. The on-chain and off-chain DAO governance approaches are summarized in the following sections.

6. On-chain governance model

The on-chain governance mechanism in DAO allows members to vote on decisions related to protocol upgrades and operations directly on the blockchain [18]. The on-chain governance model employs smart contracts and blockchain systems for transparent, decentralized decisions, facilitating members of DAO to vote on proposals using governance tokens. By performing all governance operations on the blockchain, on-chain governance ensures integrity and an immutable state of the blockchain. Voting and proposal approval occur openly on the blockchain, enabling democratic and traceable operations. In the on-chain governance model, decision-making power is distributed among all participants. It ensures that no single entity has control over the entire DAO. All administrative decisions, protocol upgrades, transactions, fund allocation, and proposals are stored on the blockchain, making them always available. This democratic and immutable nature of on-chain governance helps build members' trust in DAO. As it allows all token holders to vote on proposals, all diverse viewpoints are considered [19]. Fig. 3 shows the on-chain governance mechanism.

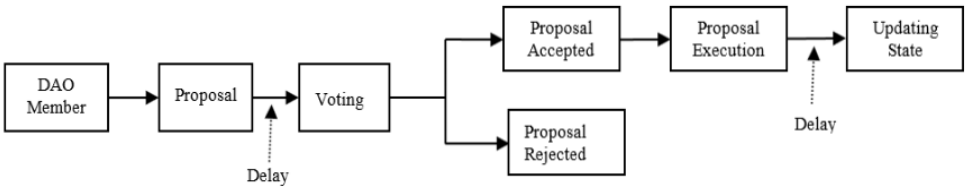

Fig. 3: On-Chain Governance Mechanism.

The on-chain governance mechanism has several key benefits to the members, such as transparency, security, and trust among participants. It stores votes permanently on the blockchain, ensuring a transparent and impartial decision-making process [20]. Members can participate in decision-making from any location by casting their votes on proposals. Automating governance operations, vote counting, fund management, and incentive mechanisms reduces operational costs and speeds up transaction processing using smart contracts. On-chain updates are faster than off-chain as they eliminate the need for intermediaries. Once participants approve updates, the blockchain is updated immediately without the need for approval from a central authority, reducing delays mostly involved with conventional governance structures. However, some factors can affect the speed of updates, such as the voting period, blockchain congestion, and governance regulations. Some DAOs add a waiting period for security purposes and conflict resolution. Even with these reasons, on-chain upgrades are faster than off-chain as the blockchain's decision-making process is directly embedded.

Despite its benefits, on-chain governance faces challenges such as low voter turnout, concentration of power due to token manipulation, smart contract vulnerabilities, implementation complexity, and susceptibility to Sybil attacks [21]. Since blockchain operations are immutable, it isn't easy to correct false votes and reverse proposals accepted due to manipulated votes. It is essential to design the voting mechanism carefully. As the blockchain network grows, the time required to settle transactions may increase, resulting in low transaction throughput and high transaction fees. It may create member retention problems, resulting in a concentration of power and less fair decision-making. Each full node must store an entire copy of the blockchain. With the growing size of the blockchain, full nodes may struggle with storage space. It makes it difficult for smaller participants to run full nodes. Moreover, it may take longer to register each vote straight on the blockchain, especially for large businesses that vote frequently.

The consensus mechanism may influence the scalability and efficiency of the on-chain DAO governance adopted [22]. PoW provides good security but struggles with energy efficiency and transaction throughput. Proof of Stake (PoS) and Delegated Proof of Stake (DPoS) enhance transaction throughput and latency while introducing differing degrees of centralization. Hybrid architectures attempt to improve

scalability while ensuring decentralization and security. Layer 2 scaling solutions may mitigate these issues; however, they introduce additional complexity. Table 3 presents an overview of the benefits and risks of the on-chain DAO governance model.

Table 3: On-chain Governance Features, Challenges, and Opportunities

Features	Explanation	Opportunities	Challenges
Transparency	– Proposals and voting outcomes are immutably stored on the Blockchain.	– Decisions are transparent – Builds Trust. – Ensures Accountability.	– Upgrade requires approval from all participants. – Slows down decisions.
Direct Participation	– Members directly participate in decision-making	– Ensures Broader Community Participation – Eliminates intermediates	– Low voter turnout results in a delay
Automation	– Smart contracts enforce decisions.	– Decisions are made directly on the blockchain	– Smart contract vulnerabilities
Immutability	– Once transactions are recorded on the blockchain, they cannot be altered – Ensures trust and accountability	– Decentralized decision making – Auditability	– Hard to fix bugs – It is not possible to reverse transactions
Security	– Every operation is recorded on blockchain, making frauds detectable. – Prevents centralized control and Manipulation. – Auditable Smart Contracts	– No Single Point of Failure. – Distributed Governance – Rewards for ethical behavior prevent malicious actors.	– Whales can dominate governance, – Governance attacks, such as Sybil attacks – Reduced Community participation
Efficiency	– Speeds up decision-making, eliminating intermediaries. – Automation and immediate execution through smart contracts. – Global participation.	– Direct and transparent decisions. – Real-time feedback – Different Voting Systems	– Revoking decisions is hard. – Vote manipulation risk. – Quick governance may not allow thorough discussion.
Inclusivity	– No need for approval from a central authority to participate in governance. – Decentralized and Community-driven decision-making.	– Encourages Diversity – Diverse governance structures.	– Requires technical knowledge. – High transaction fees – Complex User Interfaces.
Scalability	– Supports large networks for distributed decision-making	– High-speed, decentralized decision-making at scale is possible.	– High transaction fees. – Network congestion results in slow processing. – Large networks are at risk of Sybil attacks
Protocol Upgrades	– Protocols can be automatically updated via governance mechanisms. – Through hard forks, one representing the old and the other representing an upgraded protocol	– Allows continuous evolution of blockchain systems.	– Upgrade processes can be slow. – Reversing changes is difficult once implemented.
Governance Mechanisms Used	– Various voting models exist. – Token-Based Voting – Quadratic Voting. – Delegated Voting. – Reputation-Based Voting.	– Ensures innovative and fair governance approaches.	– Each governance mechanism has benefits and challenges.
Member Engagement & Retention	– Incentives like staking rewards are used to retain participants. – Governance rewards and voting participation rewards help engage active members.	– Promotes long-term participation and engagement to ensure sustainability	– Low voter turnout can lead to governance centralization – Frequent participation requirements may cause disinterest.
Incentive Mechanisms	– Rewards and incentives are given to participants who actively engage in the voting process.	– Encourages sustained engagement and decentralization.	– Vote buying and governance manipulation can happen if rewards are misused.

7. Off-chain governance model

Off-chain refers to the DAO governance mechanism, where consensus and agreement happen outside the blockchain on social platforms [20]. Off-chain offers broader participation and flexibility than on-chain governance models. Participants discuss proposals and refine ideas on social platforms. Off-chain faces challenges about transparency as debates are not recorded immutably on the blockchain. Discussions and social consensus are key aspects of off-chain governance. Bitcoin and Ethereum take the discussions on social forums like Discord and Telegram before their official execution on the blockchain. Off-chain encourages more community involvement because it does not involve gas fees for debate on social forums. As there is no legally binding, dominant community, members can influence decisions.

Decisions under the core team's and developers' guidance are important for off-chain governance [22]. Community members provide suggestions, but core team members are responsible for carrying out important functions. This facility guarantees effectiveness but can sometimes lead to centralization. In off-chain governance, proposal validation and voting occur outside the blockchain, which facilitates DAOs' reaching a consensus without paying gas fees. Members can participate in discussions without a financial burden. The final execution of the proposal depends on trusted members. Off-chain offers speedy decision-making and reduces network congestion.

The lack of transparency and security is the main challenge with off-chain governance. When a few participants influence the governance, it results in centralization. Off-chain decisions are not automatically executed and enforceable as with on-chain [23]. Off-chain governance is also susceptible to Sybil attacks. Members can create several identities to influence decisions. Off-chain governance is more flexible than on-chain governance, but it requires additional trust mechanisms and may face accountability challenges. Because of these issues, many DAOs are employing hybrid models that combine on-chain and off-chain, using the flexible nature of off-chain with the security and transparency of on-chain. Table 4 presents the features, benefits, and challenges of the off-chain governance model.

Table 4: Off-Chain Governance Model: Features, Challenges, and Opportunities

Features	Explanation	Opportunities	Challenges
Transparency	– Proposals are discussed and refined on social forums and meetings. – Once the proposal reaches a consensus, it may be brought on-chain for voting and execution.	– Allows open debate. – Encourages broader participation without transaction fees. – Prevents unnecessary blockchain transactions.	– Security and Transparency
Flexibility	– Allows thorough discussion before proposals are finalized.	– Easy to change as per conditions over time.	– Different opinions can slow down decision-making.
Member Participation	– Discussions before voting help in refining proposals.	– Encourages broader engagement as no transaction fee is involved for participating in discussions and debates	– Highly active participants can impact decisions. – Members can create multiple addresses to influence decisions
Decision-making	– Discussion and consensus on social platforms are needed to predict community interest and refine proposals.	– Voting happens outside the blockchain. – Cost efficient.	– Decisions made on forums are not compulsory to execute. – Decisions may not always be implemented and executed.
Scalability	– Governance takes place off-chain, reducing network congestion.	– Allows decision-making without blockchain transaction fees.	– Difficult to audit as forum discussions are not recorded on Blokchain.
Protocol Upgrades	– Core developers, foundations, or community votes make decisions about protocol upgrades.	– Allows experts to review upgrades before finalizing	– This may result in centralization if few core developers control decisions.
Security	– As off-chain operates outside blockchain, it is less prone to smart contract vulnerabilities.	– Reduces the risk of governance-related attacks.	– Decisions are not automatically executed, leading to delays.
Efficiency	– Decisions and discussions happen outside of blockchain without transaction fees.	– Encourages thorough discussion before making changes.	– It can slow down decision-making as it relies on human consensus.
Incentive / Reward Mechanisms	– Participants are rewarded through reputation, influence, or off-chain incentives.	– Encourages broader participation in governance discussions.	– Lack of direct financial incentives may lead to reduced community engagement.
Dispute Resolution	– Governance councils, foundation decisions, or community votes are used to settle disputes.	– Permits customized solutions as opposed to predetermined code-based results. – .	– Favoring centralized decision-makers or introducing prejudice. – Few members can dominate decisions.
Decision Implantation	– Developers or governance groups must manually apply decisions made off-chain.	– Adaptability in decisions according to actual conditions.	– Decisions may be delayed or ignored, as decisions are not binding.

8. Mechanism of DAO governance

The mechanism governing DAOs depends on the type of governance models, such as on-chain, off-chain, or hybrid. In the on-chain governance model, the governance mechanism is directly embedded into the blockchain, allowing every member to participate in decision-making [24]. This model permits members to vote on proposals, submit proposals, and propose protocol changes. Off-chain discussions are held on social forums, and proposal execution requires approval from trusted members [25]. The hybrid model combines the benefits of on-chain and off-chain to provide a more balanced governance structure. Fig. 4 depicts a hybrid governance mechanism.

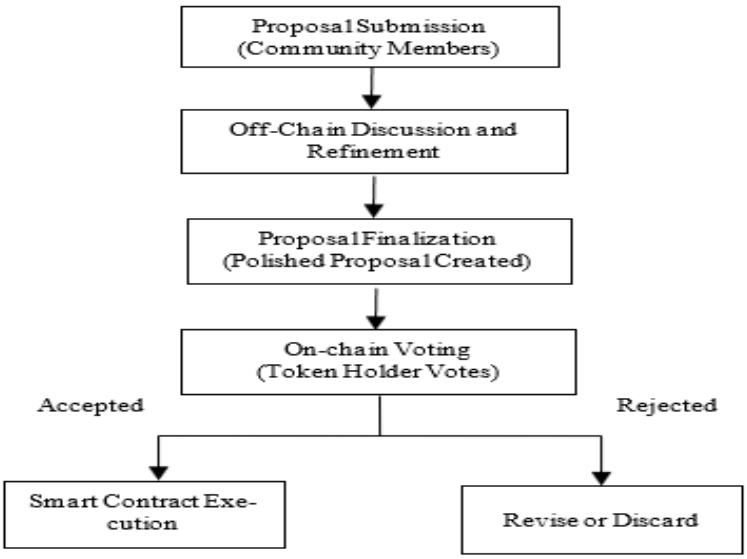

Fig. 4: Hybrid Governance Mechanism.

The process governing DAOs varies depending on the application, blockchain design, and governance framework [26]. The following section illustrates the steps for DAO governance operation.

a) Proposal Submission

On-chain governance starts when the token holder submits a proposal to update software, fund allocation, or any other operational decisions related to DAO [29]. Different governance models, such as on-chain, off-chain, or hybrid, may have different proposal submission requirements. To submit a proposal, the proposer has to satisfy certain criteria, such as possessing a specific number of tokens, to confirm that the submitted proposal is in line with the purpose of the DAO. The proposal must be aligned with the objective of DAO, realistic, and contribute to its growth and sustainability.

b) Community Feedback

Community discussion is very important after a proposal has been submitted to assess its relevance, advantages, drawbacks, and impact on sustainability. The discussion process depends on the type of governance model, such as on-chain, off-chain, or hybrid. The on-chain governance model is less interactive than the off-chain one. On-chain, discussions happen through formal governance portals directly on the blockchain and are directly stored on the blockchain, maintaining the immutable nature of blockchain. Proposals are executed through smart contracts, and a voting mechanism is used once approved. In off-chain governance, members present a proposal on social media forums or platforms such as Twitter, Telegram, etc., and discussion happens on social forums. Depending on community feedback, the proposal may be refined, accepted, or rejected. The accepted proposal is then submitted to the blockchain for voting and execution.

c) Voting on the Proposal

Once the proposal receives acceptance from the community, the next action depends on the type of governance model, such as the on-chain, off-chain, or hybrid model [29]. As DAOs are designed to operate autonomously, smart contracts play an important role in the verification and execution of proposals. In the off-chain governance model, after community approval, the proposal requires multi-signature approval from trusted members for execution. These multi-signature wallets often depend on smart contracts to enforce predefined conditions, such as the need for approval from trusted members before executing the operation. In on-chain, members cast votes directly on the blockchain. The smart contract automatically executes the requested operation if the vote passes a certain threshold.

DAOs employ different voting mechanisms, such as token-based, delegated, quadratic, and reputation-based methods. On-chain offers full decentralization and security, resulting in high transaction fees and slow transactions. On the other hand, the off-chain is faster, cheaper, scalable, and community-driven, reducing storage space compared to the pure on-chain model. However, it lacks automated execution and is susceptible to vote manipulation, making it unsuitable for financial transactions involving large stakes and legal governance. The hybrid model combines the security and automation features of the on-chain model with the cost-effectiveness of the off-chain to form a more balanced governance model.

d) Reaching a Decision

Proposal validation depends on the type of governance mechanism, such as quorum requirements or preset threshold [29, 30, 31]. A quorum is the minimum number of votes required to pass the proposal. Without a preset quorum, proposals are either rejected or postponed. Quorum requirements, such as fixed quorums, dynamic quorums, or percentage-based quorums, depend on the design of the DAO. In approval threshold methods, a simple majority, which requires fifty percent approvals, or a super chatty, which ensures a higher percentage of votes, may be used to provide broader community participation in decision-making. A low quorum requirement may lead to centralization, whereas a high quorum can lead to indecision.

e) Implementing the Approved Change

Once the proposal is approved, the next stage is implementing and executing the decision. The execution of the proposal depends on the type of governance model. On-chain governance models automatically execute decisions through enforceable self-executing smart contracts once approved. Off-chain governance decisions are executed manually and require trusted individuals to approve execution. In the Hybrid model, approval may take off-chain and final execution on-chain, combining the benefits of on-chain and off-chain.

f) Continuous Improvement

On-chain governance is an interactive process, permitting DAOs to change over time. The community continually evaluates how the system is functioning and can propose changes to improve it. This adaptability helps the blockchain to evolve, addressing new challenges and incorporating advancements to serve its users better. Advancements such as AI-driven decision-making and cross-chain governance models can enhance member engagement and fairness. Continuous improvement is essential for the long-term sustainability of DAOs, ensuring that governance remains adaptive, efficient, and aligned with the community's evolving needs. Following these steps, on-chain governance empowers blockchain communities to manage and update their networks decentralized and transparently, ensuring all stakeholders has a voice in decision-making.

9. Voting mechanisms in DAO

Voting mechanisms are the backbone of DAO governance. DAOs rely heavily on smart contracts to operate [23]. Smart contract programs execute operations automatically when consensus between participants is reached through voting. This mechanism allows every member of the DAO to vote on key decisions of the DAO to ensure that governance remains decentralized, transparent, and efficient [26]. Understanding voting mechanisms is very important as they directly impact the governance and effectiveness of DAOs. Voting mechanisms determine how proposals are submitted, debated, and refined, impacting member engagement, decision quality, and sustainability. The selection of the voting mechanism depends on the design of the DAO, governance structure, level of decentralization, and security. The following section explores different voting mechanisms used by DAOs, their application in various governance models, and their benefits and drawbacks.

9.1. Token-based voting

Token-based voting is the most employed method in which the voting power of a participant is proportional to the number of tokens the stakeholder holds [28]. It means that stakeholders with more tokens have a major influence on decisions. However, it can lead to centralization as stakeholders have many token control decisions. In the on-chain governance model, votes are directly stored on the blockchain, ensuring transparency and immutability, but with higher gas fees. Many organizations require a minimum percentage of members to participate in voting to ensure that many members make decisions.

In off-chain governance, voting and discussion occur on community forums, and approved decisions are executed manually. In a hybrid mechanism, discussions happen outside the blockchain on community forums and are implemented with final decisions on-chain. Token-based voting can lead to decentralization if a few stakeholders hold large tokens and control decisions. Token-based voting may struggle with domination by wealthy stakeholders, low voter turnout, governance attacks, and high gas fees.

9.2. Majority voting

Majority voting is the most basic voting mechanism in DAOs, where the proposal is accepted if it receives more than 50% of the votes [29]. This system is simple, transparent, effective, and often used since it ensures the participation of the majority of stakeholders in decision-making. In on-chain voting, the entire process can be automated using smart contracts. Stakeholders vote using governance tokens; smart contracts automatically enforce decisions and records on the blockchain. Majority voting offers secure, transparent, and tamper-proof decisions. However, it also faces challenges such as member retention due to high gas fees, dominance by large token holders, and vulnerabilities in smart contracts. Frequent proposals can lead to the disinterest of participants in voting.

9.3. Supermajority voting

A supermajority is a voting mechanism where a proposal requires approval from a higher number of voters (mostly 66%, 75%, or more). This model is most used to ensure agreement on important proposals from most members. It prevents the risk of centralization by wealthy stakeholders. Supermajority is often used for fund allocation, protocol upgrades, and governance changes where agreement from a majority of stakeholders is important to build trust and maintain stability [29]. In on-chain governance, smart contracts automatically enforce voting thresholds. The proposal is automatically executed if it receives more votes than the threshold.
Off-chain decisions happen outside the blockchain on social forums before being manually executed on the blockchain. In hybrid models, decisions and voting happen outside the blockchain, and final execution happens on the blockchain. Supermajority voting ensures broader agreement and prevents whales from dominating decision-making. It enhances stability and reduces the risk of governance attacks. Supermajority voting in DAO faces challenges such as low voter turnout and decision deadlock due to a high threshold.

9.4. One-token one-vote

One-Token One-Vote is a type of token-based voting. Every token gives one vote to participants, so the more tokens someone has, the more impact on the decision. In the on-chain governance model, voting takes place directly on the blockchain, and decisions are enforced automatically through smart contracts [29, 30]. On-chain governance ensures that every vote is recorded on the blockchain immutably and transparently. On-chain one-token one-vote can become slower and more expensive due to high gas fees. Off-chain makes the process cost-effective, efficient, and faster by keeping voting and discussion outside the blockchain. As this method relates voting power directly to investment in DAO, large token holders can influence decisions.

9.5 Quadratic voting

Quadratic voting is designed to limit the dominance of wealthy stakeholders by making additional votes expensive [29, 30]. This ensures the impartial and decentralized nature of DAO. But it makes the voting mechanism complex. Smart contracts calculate quadratic costs and validate transactions. It prevents tampering but requires additional computational power and storage space. Off-chain employs quadratic voting on social platforms and executes operations manually. Quadratic voting promotes fairness by reducing the influence of whales on decisions. However, this method is computationally expensive and difficult to implement.

9.6. Reputation-based voting mechanisms

Reputation-based voting mechanism allocates decision-making power to participants in proportion to their contribution, engagement, and achievement in DAO [29], [31 - 33]. Unlike token-based voting, where decision-making power favours whales based on token holdings, reputation-based governance ensures that those who contribute to the DAO influence decisions. This approach ensures that participants contributing to the DAOs have more influence over decisions.
Members gain a reputation by participating in debates, completing tasks, and providing resources. Some DAOs reduce members' reputations due to inactivity over time to keep members engaged. Submitting and validating proposals increases members' reputations. Taking specific responsibilities also enhances members' reputations. As the reputation cannot be transferred, bought, or sold, reputation-based systems resist Sybil attacks. Combining reputation-based voting systems and consensus mechanisms can further enhance resistance to Sybil attacks. Reputation-based systems are complex to implement. It leads to disputes if the assessment conditions to determine reputation scores are not transparent. Members can participate in activities that increase their reputation without contributing to the DAO.

9.7. Delegated voting

A delegated voting mechanism, or liquid democracy, enables members to participate directly in the decision-making process or delegate their voting rights to trusted participants [29]. This flexibility allows participants who don’t have time or knowledge to delegate their voting rights to more informed, trusted members. Assigning voting rights to a few members may speed up the decision-making process. Voters can give voting rights to experts with more knowledge and expertise on specific subjects.
Delegation is not permanent; voters can revoke their voting rights to cast their votes directly. Snapshot, Compound, and MakerDAO are some examples that utilize delegated voting mechanisms. If too many voters delegate their voting rights to a few community members, it leads to centralization, contrasting the decentralized nature of DAOs. In delegated voting, delegates are expected to act according to the members’ interests. But sometimes, this alignment is not guaranteed.

9.8. Holographic consensus

Holographic consensus is an innovative voting mechanism that promotes effective decision-making while preserving decentralization [27, 30]. The basic idea behind holographic consensus is to combine the workings of prediction markets into a voting process. In this model,

participants believe that a proposal will pass or be rejected, and they stake tokens to indicate confidence in their forecasting. Those who predict correctly receive an award. Those who predict incorrectly may lose part or all of their investment.
This mechanism encourages participants to analyse proposals, promoting thoughtful decision-making carefully. In on-chain governance, smart contracts manage token staking, vote counting, and the distribution of rewards. In the off-chain, staking and prediction market functionalities happen outside the blockchain to reduce costs and promote scalability. The mechanism ensures that only genuine proposals will succeed. The limitations of this method are its complexity, low participation, which results in low-quality proposal approvals, and high gas fees.

9.9. Time-lock voting

Time-lock voting enhances security by incorporating time-based constraints in the voting mechanism. This method can use vote-escrowed tokens and time-lock puzzles [6]. In the Vote-escrowed tokens mechanism, participants lock tokens to increase voting power for a pre-set period. Voting power gained is in proportion to the lock period. Voting power is aligned with the sustainability of the DAO. Participants who have an extended duration of holding tokens have an increased influence on decisions. A time-lock puzzle is a cryptographic method that protects information for a specific period. Cryptographically locked data remains confidential until a specified time elapses. Attempting to unlock information before the time is impossible due to such algorithms' planned design.
In an On-chain, time-locked protocols are implemented through smart contracts. Off-chain time-lock protocols operate outside the blockchain. The hybrid method combines on-chain and off-chain elements to enhance efficiency and security. These protocols ensure that sensitive information remains confidential until a predetermined time. These protocols enhance security by preventing premature access to information. Once information is locked for a specific period, releasing it before the time may become challenging. In some time-lock implementations, continuous processing is essential to ensure delay, which may increase resource utilization.

9.10. Ranked-choice voting

This method enables participants to rank proposals based on their preferences. It reflects the interests of the broader community [34]. Smart contracts allow members to rank proposals. Smart contracts carry out various operations, such as counting first preferences, eliminating proposals with few votes, and reallocating votes. RCV promotes more democratized decision-making. In off-chain, votes can be accumulated off-chain and executed on blockchain by trusted members; implementation of RCV is complex, but a well-planned implementation reflects the interests of the community.

10. DAO governance challenges

Decentralized autonomous organizations offer a democratic, decentralized, and transparent governance structure by providing decision-making power to participants without the need for a central authority. However, DAOs face several governance challenges that impact their efficiency and long-term sustainability [29], [35]. The following are key challenges in DAO governance, with real-world examples and possible solutions.

10.1. Low voter turnout

Low voter turnout is one of the most common challenges in DAO governance [35]. Every proposal in DAO needs the approval of participants through a voting mechanism. Most members do not have the time to vote or lack sufficient knowledge about the proposals. Many proposals are highly technical; only members with knowledge of protocols can understand them. A lack of information about proposals results in voter disengagement.
In an on-chain governance mechanism, every vote requires a transaction fee. If these gas fees are high, small stakeholders may not participate in the voting [34], [35]. In token-based voting systems, members who have many tokens influence governance and decision-making. Small stakeholders may feel their vote will not impact decisions, resulting in low voter turnout. Many members do not participate in voting without direct rewards or incentives like traditional organizations. In delegated voting systems, members assign their voting rights to trusted representatives. However, these delegates may not always vote in the interest of those they represent or may fail to participate altogether. In large DAOs, members may also ignore frequent proposals as they require too many votes.
Low voter turnout in DAO can have a serious impact. If voter engagement is low, it may give governance to few members, contradicting the decentralized principle of DAOs. DAOs become vulnerable to attacks. Malicious actors can take control of DAO, exploiting funds and important resources. Decisions may not represent the broader community. If governance fails due to low voter turnout, long-term holdups may occur for proposals. Addressing voter disengagement needs both technical and reward-driven mechanisms. DAOs can employ affordable on-chain operations using layer-2 solutions, batch transactions, quadratic voting to reduce the impact of whales, and automated alerts to voters using smart contract mechanisms. Rewards, incentives, and reputation scores for active participation can also improve member engagement. Automated AI tools can also filter, summarize, and reduce the number of proposals.

10.2. Governance inequality and whale domination

In token-based voting systems, voting power is directly proportional to the number of tokens a participant holds. This relates to the member's investment or financial stake in the DAO. Malicious members can purchase many tokens to influence Dao's decision-making [21], [29]. This allows wealthy members to possess many tokens to influence decisions in the DAO. It can lead to centralization by giving decision-making rights to the rich.
Fraudsters can distribute tokens to multiple addresses to appear as various voters, resulting in a Sybil attack. A well-known example is Uniswap. In Uniswap, large organizations have used UNI tokens to impact governance decisions, ignoring community interest. Quadratic voting can be used to reduce whales' dominance, making additional votes expensive. Reputation-based voting methods can also be used where reputation score and governance increase with a contribution to the DAO instead of token holdings. Requiring tokens to be held longer and using multi-signature wallets can also help mitigate this issue.

10.3. Smart contract vulnerabilities

Smart contracts form the foundation of DAO governance by handling tasks such as voting, membership management, treasury control, and contract terms execution [29, 36]. However, vulnerabilities in smart contracts may lead to financial losses, governance manipulation, and loss of reputation within the community. Malicious actors can exploit these vulnerabilities to impact on-chain and off-chain governance [37]. Experts must identify the most common vulnerabilities, their impact, and mitigation strategies.

The 2016 DAO attack is a well-known example of a reentrancy attack. In most common reentrancy attacks, the attacker repeatedly executes the vulnerable smart contract function before updating the state. Integer underflow or overflow happens when a numeric variable surpasses or drops below its limit. Attackers can use this flaw to generate additional tokens, resulting in the manipulation of votes. In front-running attacks, attackers find pending transactions and submit their proposals with higher transaction fees, exploiting transaction sequences for personal advantage. Mitigation strategies involve commit-reveal voting and batch processing to prevent manipulation of a transaction sequence. Many DAOs rely on Oracle for price information, governance decisions, and fund management. An Oracle manipulation attack occurs when an attacker manipulates an external data source. If an oracle is manipulated, the attacker can feed manipulated data. DAOs can employ decentralized oracles, price mediatization techniques, and circuit breakers to avoid oracle manipulation attacks.

Additionally, some DAOs employ upgradable contracts to upgrade the functionalities of contracts over time. Attackers can use this mechanism to introduce unauthorized upgrades to favor them [39]. Multi-signature approvals and keeping important functions in immutable contracts can prevent illegal takeovers. Gas griefing, data exposure, time dependence, and denial of service are significant inclusions in the list of vulnerabilities on smart contracts. Smart Contract vulnerabilities do not cause technical failures but result in governance manipulation. Risks like compromised voting, drained treasury, and proposal hijacking pose significant dangers to on-chain governance. Frequent exploits can result in a loss of trust within the community and lower participation. Smart contract audits, immutable contracts, and fail-safe mechanisms can reduce risks due to vulnerabilities. Secure governance mechanisms, such as quadratic voting, reputation-based systems, and multi-signature wallets, can prevent governance manipulation and ensure member engagement.

10.4. Complex coordination and decision making

The decentralized nature of DAOs often slows down decision-making. Achieving agreement on proposals within a community can become challenging [6], [29], [39], [40]. In DAOs, off-chain governance relies on open discussions on social platforms, which can result in delays due to prolonged talks. Without a traditional hierarchical structure, leadership, and centralized authority, DAOs may struggle to respond to important matters. DAO decisions represent the interests of the majority community and inform decisions through agreement within the community. DAO decisions may encounter difficulties in their implementation and effectiveness, even though they are determined by informed community consensus and reflect the interests of the majority community. If the decision-making process slows down, it decreases member participation and increases inefficiency in governance.

DAOs can be divided into subparts, each responsible for a specific task. These subgroups can speed up decision-making while working per a larger organization's rules and are accountable to the parent DAO. Automating some routine operations of DAOs using smart contracts can also help process proposals faster. Time-limited decisions and voting periods also help reduce delays and ensure proposals are executed within a specific period.

10.5. Legal and regulatory uncertainty

DAOs lack recognition as legal organizations in most jurisdictions. DAOs face taxation, compliance, and conflict resolution challenges without a clear legal framework. As DAOs are designed to work independently without a central authority, they do not fit into existing legal frameworks [6], [29], [39], [40]. Most jurisdictions do not consider DAOs as legal organizations, which creates problems in contract enforcement and dispute resolution. Without legal recognition, it becomes difficult for DAOs to raise funds. In conventional organizations, individuals are protected from being held responsible for debts and legal violations by companies and Limited liability companies (LLMs). If DAOs engage in activities that violate laws, members who participated in voting may be held individually.

DAOs mostly engage in financial operations such as raising funds, decentralized finance (DeFi), and payment solutions, which generally fall under the financial regulation category. Many governments suspect that DAOs fail to comply with anti-money laundering regulations and financial laws if they operate autonomously without legal frameworks. As DAOs may facilitate financial transactions on a global scale, compliance with different jurisdictions becomes more complex as other nations have different regulations. Traditional organizations have clear tax structures, but DAOs don’t have a way to pay taxes or report capital gains and profits.

To address these legal uncertainties, DAOs are finding ways to comply with regulations while maintaining their decentralized and democratic structure. One approach is registering DAOs as Limited Liable Companies (LLMs), Foundations, or cooperatives. Legal wrappers help to protect DAO members from being personally held liable and comply with legal regulations [29], [40]. Another approach is by adopting governance that aligns with legal structures. DAOs may use Know Your Customer to ensure that the governance structure follows anti-money laundering regulations. Some DAOs are adopting a model where some key operations, such as fund management, comply with the legal framework while the rest remain decentralized.

10.6. Identity verification problem

A significant challenge DAOs face is the identity verification of members, as in blockchain, the identity of participants is protected [41], [42]. Attackers can create multiple wallet addresses to manipulate the governance of DAOs, leading to Sybil attacks. Sybil's attack allows the member to increase their influence in decision-making, compromising the decentralized and democratic structure of DAOs. To address the identity verification problem, we can use Proof-of-Personhood to verify the uniqueness of participants and SounBound tokens (non-transferable identity-based tokens) to identify an individual's contributions to the DAO, respectively. Additionally, DAOs can employ reputation-based systems to determine members' past contributions and engagement.

10.7. Financial stability and sustainability

For DAOs, Sustainability relates to financial stability and their long-term existence, effective governance, and community engagement over time [29], [40], [42]. Many DAOs initially secure funds through donations, venture capital, or token sales. Later, they may struggle

to maintain a sustainable flow of funds and adapt to changing conditions. Shortage of funds, financial mismanagement, accountability, poor governance structure, and reduced community participation can significantly challenge the sustainability of DAOs. Without an effective mechanism, DAOs may struggle to attract contributors and maintain their decentralized and democratic structure.
To ensure long-term existence, DAOs must use diverse strategies to maintain their treasuries and attract the community. Varied approaches to raising funds, such as staking, service fees, or incentive mechanisms, may help preserve financial stability. Building a resilient governance structure is essential to ensure broader community engagement and avoid centralization. Furthermore, a clear operation framework, transparent governance, and regular clarity can sustain member participation. Emergency response and disaster recovery mechanisms can help DAOs withstand financial crises due to vulnerabilities or governance failures. For long-term viability, DAOs must create a sustainable ecosystem that balances financial stability and decentralization.

10.8. Scalability challenge

As DAOs expand in size and population, they add several benefits but also face significant challenges to scalability and consensus mechanisms [43]. In small DAOs, decisions can happen quickly and collectively. However, as DAO expands, governance becomes complex, leading to slower decision-making and higher transaction fees. In the case of on-chain governance, each proposal requires validation through a voting mechanism over the blockchain and needs gas fees. This gas fee increases as DAO expands, making participation expensive and resulting in the disengagement of participants.
One of the biggest impacts of the growing size of DAO is governance delay [44]. In the on-chain governance model, reaching an agreement can take as long as the number of transactions and voters increases. Proposals may get delayed as reaching consensus becomes more complex. As a DAO expands, it becomes a more attractive target for attackers. Malicious actors can acquire many tokens to manipulate governance, known as a 51% attack. Conversely, larger DAOs benefit from more resources, funds, talent, expertise, and ideas. To address scalability challenges, DAOs can implement Layer-2 scalability solutions to reduce gas fees and increase efficiency. These solutions minimize network congestion and ensure that a governance action remains cost-effective.

11. Recent trends in DAO governance

To address governance challenges and meet community needs, decentralized autonomous organizations (DAOs) are continuously improving their technology and governance mechanisms. As DAOs expand in size and membership, they face increasing challenges in complying with legal regulations [29], speeding up transaction processing, and enhancing security. This section examines new advances in DAO governance, emphasizing significant advancements that will likely influence how decentralized organizations operate.

11.1. Hybrid governance and sub-DAOs

Full on-chain governance ensures transparency but leads to slow decisions and high transaction fees as the DAO expands. To address this challenge, DAOs adopt hybrid models combining on-chain and off-chain [44], [45]. Sub-groups are used to speed up transactions to increase operational efficiency. On-chain executes all transactions via smart contracts. In hybrid models, voting is off-chain on social platforms, and execution is on-chain. It allows DAO to discuss and refine proposals off-chain, incurring no gas fees.
Many DAOs are dividing themselves into sub-DAOs to improve governance efficiency. Instead of the entire community making decisions on every proposal, sub-DAOs can be formed to handle specific responsibilities. Deciding decision-making power to specialized teams or sub-DAOs can reduce governance delay. A key concern in hybrid models is that sub-committees may gain disproportionate control over decision-making. It can lead to governance manipulation, where a few entities can dominate decisions. Combining hybrid models and sub-DAOs allows for maintaining the decentralized and transparent nature of DAOS while improving efficiency.

11.2. Reputation and non-token voting systems

A rising trend in DAO governance is reputation-based systems where influence power is calculated by the contribution and involvement of participants in DAO [46]. One approach to reputation-based governance is SoulBound Tokens. SBTs are permanently assigned to members and ensure voting power is based on contribution instead of financial investment. Another trend is that the reputation score ensures voting power is assigned based on contribution and involvement rather than token holdings. A reputation-based system encourages long-term contribution, ensuring long-term contributors participate in decision-making rather than short-term traders.

11.3. AI-assisted DAO governance

Nowadays, AI is transforming every field, and DAOs are no exception. AI improves decision-making, predicts risks, and reduces governance mistakes. As DAOs grow, evaluating every proposal manually and predicting risk is difficult. AI-driven tools can help analyze proposals, predict risks and outcomes, and vote for recommendations based on historical data and community interests [47]. AI tools can assist in identifying duplicate proposals, identifying security vulnerabilities, and managing funds. Several DAOs like Gnosis and DAOstack are already using AI in governance. Despite several benefits, the challenge with AI-assisted governance is that AI algorithms can get biased based on historical data [48].

11.4. Cross-chain and interoperability

With the expansion of the blockchain ecosystem, cross-chain and interoperability between different blockchains became essential [49]. DAO Governance is now involving multiple blockchains. It allows cross-chain operation and interoperability, reduces transaction costs, improves scalability, and ensures broader community engagement. Polkadot already uses cross-chain governance, allowing members from different blockchains to participate in decision-making [50]. By implementing Layer-2 solutions to improve interoperability, DAOs can reduce gas fees and enhance transaction speeds and security. Despite several benefits, Cross-chain DAOs face challenges regarding governance fragmentation and security. Cross-chain bridges used for funds and governance data transfer are vulnerable to attacks. Furthermore, managing multiple DAOs across various platforms can become challenging.

11.5. Legal wrappers

DAOs have started turning to legal wrappers like LLCs and cooperatives to gain government recognition and lessen regulatory uncertainty [50]. Wyoming and Tennessee have legalized DAOs as LLCs, with dOrg and Opolis registering under these frameworks. Some DAOs need governance participants to undergo KYC to comply with regulations. It enhances legal safeguards and authorization from regulators.

11.6. Improved revenue generation

DAOs must ensure long-term sustainable income as they evolve [1, 29]. Many DAOs are switching from selling tokens and offering incentives to diverse revenue sources to generate more steady and regular income. Membership and service-oriented income let DAOs charge for governance or tools. Aragon DAO monetizes its governance architecture by helping other DAOs create and administer decentralized decision-making systems. DAOs use yield-generating funds to obtain passive revenue via decentralized finance (DeFi) mechanisms. Yearn Finance and other DAOs invest in yield farming, financing, and competing to maximize earnings and ensure financial stability.

DAOs can minimize token generation and fundraising using DeFi methods to construct self-sustaining financial models. However, these treasury management tactics are risky. Poor administrations might misallocate assets, overexpose to uncertain markets, and lose due to DeFi protocol security flaws. DAOs use structured treasury rules, automated asset allocation, and diverse investment methods to reduce these risks. Treasury management is essential for future viability and resilient markets as the DAO ecosystem evolves.

12. Case studies: MakerDAO and Aragon

This section analyses MakerDAO and Aragon, two key DAOs. Assessments cover governance structures, voting processes, decentralization, success rates, problems, and new trends. Details on their distinctive features and development, and operation lessons are also offered. Case studies try to explain how DAOs work in real life and what factors affect their performance and evolution.

12.1. MakerDAO

MakerDAO is among the first and most significant DAOs founded on the Ethereum network. The Maker Protocol makes it possible to create DAI, a decentralized stablecoin based on the US dollar [52]. MakerDAO uses a token-based voting mechanism where MKR token holders vote according to their holdings. Governance polls measure community opinion on proposed changes, and executive votes implement them in the protocol. MakerDAO's vote delegation feature lets MKR holders give voting authority to trustworthy delegates to boost participation and prevent voter indifference [53]. Additionally, elected governance facilitators oversee vote logistics and proposal coordination, while core units provide operational duties, including risk assessment and protocol creation. These units need approval from MKR holders using the same voting method.

MakerDAO has become a paradigm for cryptocurrency DAOs due to the adaptability and resiliency of its governance system [54]. Strong integration in DeFi, open procedures, and a robust governance mechanism are the main reasons for the DAOs success. Many platforms have incorporated DAI, and MakerDAO has shown flexibility by implementing measures such as allowing various kinds of collateral and launching real-world assets (RWAs). To be flexible, MakerDAO allowed different types of assets to be utilized as security. Many companies use DAI. But it still must deal with several problems. There is centralization of power when only a few people own a lot of MKR tokens.

It can be hard for frequent users to comprehend or participate in the governance system. It's also risky because the collateral's value can change quickly, and regulators are becoming more worried about how these systems are run [55]. Through asset diversification, overcollateralization, and technologies such as the Peg Stability Module, MakerDAO aims to mitigate regulatory issues and collateral volatility. It also seeks to streamline governance and increase legal clarity to encourage wider involvement.

12.2. Aragon

Aragon is a platform that facilitates the establishment and administration of DAOs. Launched in 2017, it provides a governance architecture that is both modular and adaptable, enabling users to create DAOs without the need for extensive technical knowledge. Aragon Network Token (ANT) holders are in charge of governance; they cast votes on matters like protocol updates, treasury distributions, and strategic orientation [29]. Aragon is notable for its meta-DAO concept, allowing it to govern itself and facilitate the development of additional DAOs. In contrast to MakerDAOs tight financial focus, Aragon OSx emphasizes customizable governance. DAO governance models include token-based, reputation-based, and committee-based approaches. Because of its adaptability and user-friendliness, Aragon is a popular DAO launch platform.

In addition to supporting various governance systems, the platform also includes the Aragon Court to resolve disputes [29]. Despite this, Aragon struggles with issues such as disagreements over its internal governance, concerns regarding its potential to remain viable over the long run, and growing competition from more recent decentralized autonomous organization platforms. Another factor that has impeded its expansion is the lack of legal clarity and the limited acceptance in specific regions. Because of this, Aragon has prioritized enhancing the user experience, increasing modularity, and encouraging interoperability with other DAO technologies to maintain its competitiveness and relevance.

13. Discussion

DAOs are expanding quickly. Over 13,000 DAOs oversee over $24.5 billion in assets as of 2024 [56]. Active engagement of participants is still low. Few individuals vote or submit proposals even though millions own governance tokens. A small number of DAOs account for most of the activity. Many organizations have improved this by using new voting techniques, including quadratic voting, which gives smaller holders more influence, and delegated voting, in which users choose representatives to vote on their behalf. By offering gasless voting, platforms like Snapshot eliminate the financial burden of blockchain transaction costs. Other techniques, such as reputation-based voting and participation incentives, are also being investigated to boost turnout and make the government more dynamic and inclusive.

The attack in 2016 on DAO, which operated on the Ethereum blockchain, is considered one of the most significant events in the history of DAOs. In response, the Ethereum community devised a strategy to reclaim the stolen assets by dividing the blockchain in half. Because of this, it became clear that depending on code might be problematic and that human judgment and the community's agreement are also required. Since then, most DAOs have implemented safety measures such as pause mechanisms, improved code audits, and more transparent voting procedures to prevent similar problems [29].

Looking at previous DAOs, we can better understand what works and what does not. For instance, MakerDAO and MolochDAO have succeeded by establishing transparent rules, cultivating robust communities, and implementing flexible decision-making processes. For example, MakerDAO could withstand a significant market meltdown in 2020 by utilizing its governance procedures to make rapid adjustments. On the other hand, efforts such as YAM Finance and Beeple's B20 DAO were unsuccessful because of flaws, poorly designed incentives, or governance that was not transparent. In just a few days, ConstitutionDAO was able to gather $47 million, but it could not win its auction and had problems with refunds. For a DAO to be successful, it is necessary to have both technological security and community trust [57].

One of the most significant ethical challenges that DAOs face is balancing decentralization and accountability. Complete decentralization might make it difficult to assign responsibility if something goes wrong, while excessive central control can directly oppose the fundamental principles underpinning blockchain technology. Vitalik Buterin, one of the co-founders of Ethereum, has written about the necessity of "credible neutrality" systems, which are defined as those that are impartial and not controlled by any party. There are already a lot of DAOs that employ governance models. These models mix on-chain voting with off-chain discussions on Discord or forums. This combination enables communities to discuss ideas before making formal votes, improving the voting process's fairness and flexibility [58].

Both off-chain and on-chain techniques have advantages and disadvantages when comparing governance structures. MakerDAO and Compound employ on-chain governance, which offers automation and transparency but may be costly and complicated. Coding errors are frequently irreversible. Off-chain solutions used by ENS DAO and Uniswap depend on social consensus and offer greater flexibility, but they can also result in unofficial power structures. These days, hybrid models incorporating both strategies are popular and appear to provide the greatest outcomes regarding involvement and flexibility [59]. Effective instances demonstrate the necessity of adjusting the government to the community's requirements. For example, completely on-chain systems perform well in financial protocols that need automatic execution and transparency, but off-chain DAOs can be more appropriate for creative or social organizations.

For small DAOs, simple and affordable tools are often best. Small communities may easily and affordably build DAOs using platforms such as Snapshot (gasless voting), Gnosis Safe (for handling money), and templates from DAOhaus or Tally. These tools don't require much technical expertise and are simple to use. Large DAOs like MakerDAO or Aave, on the other hand, require more sophisticated mechanisms. For regulatory clarity, they frequently mix delegated voting, layered decision-making procedures, and legal wrappers like Wyoming DAO LLC registration with completely on-chain frameworks like Compound's Governor Bravo or OpenZeppelin governance modules. These configurations support the safe operation, scalability, and efficient management of big treasuries of DAOs.

Artificial Intelligence (AI) also offers new possibilities for DAO governance. AI tools can help predict voter behavior, detect malicious activity, and even recommend when to vote. However, these tools must be transparent and fair to avoid centralizing power in the hands of those who control the algorithms [60]. In the future, AI and machine learning may support more scalable, data-driven governance without replacing the core value of community-driven decisions.

14. Conclusion

Decentralized Autonomous Organizations are transforming traditional governance by enabling transparent, community-led decision-making through blockchain and smart contracts. With an emphasis on on-chain and off-chain models, this study examined DAO governance from an architectural, technological, and ethical standpoint. Although on-chain governance guarantees automation, security, and transparency, it has drawbacks, including scalability, high prices, and voter apathy. Off-chain governance may sacrifice transparency and enforcement, but it provides flexibility and involvement without gas costs. However, issues like token concentration and governance inequality still exist. Hybrid approaches integrating both advantages are gaining traction, as seen in successful projects like MakerDAO and Aragon. For smaller DAOs, platforms like Snapshot and DAOhaus offer low-cost, user-friendly governance solutions. Larger DAOs benefit from fully on-chain frameworks like Governor Bravo and legal wrappers to navigate regulatory concerns and enforce accountability. Cross-chain coordination, real-world testing of hybrid governance, and creating governance frameworks that dynamically adjust to community growth and security risk should be the main areas of future DAO research and development. Including AI-powered technologies to help with risk prediction, proposal summarization, and decision analysis might improve governance effectiveness. Furthermore, long-term survival will depend on DAO structures aligning with legal requirements through formal wrappers and compliance-ready designs. Developing DAO governance would require careful design that balances decentralization with inclusion, trust, social responsibility, and technology.

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