

The Potential of Decentralized Autonomous Organizations for Enhancing Inter-organizational Collaborations for Critical Infrastructure Resilience

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Ensuring Critical Infrastructure Resilience (CIR) hugely relies on decisions and actions made by networks of public and private stakeholders and their inter-organizational collaborative capabilities. Public-Private Collaborations (PPCs) are currently the most prominent approach for building CI resilience all around the world, but still face many obstacles and challenges. The Decentralized Autonomous Organization (DAO) paradigm, enabled by blockchain technology and smart contracts, provides the conceptual and technological means for new kinds of decentralized systems and allows for the emergence of new ways of governance and coordination for CIR.

The paper explores the potential of DAO for enhancing governance, decision-making, and coordinated resource management in order to tackle the current challenges of cross-organizational collaboration in CIR. It does so by critically comparing the traditional multi-actor governance models and the innovative DAO governance approach, taking the main objectives of PPCs and their current challenges in CIR as conceptual lenses. The key aspects of network governance are discussed, along with the advantages/shortcomings of different approaches, and their implications in the context of PPCs for CIR. This explorative study paves the way for both new streams of theoretical research and blockchain pilot projects in real contexts.

Keywords: Critical Infrastructure Resilience, Decentralized Autonomous Organization (DAO), Governance, Decision-making, Public-Private Collaboration (PPC)

1. Introduction

Modern societies and their prosperity are increasingly dependent on essential services provided by Critical Infrastructure (CI). Critical Infrastructure Resilience (CIR) is emerging as one of the essential issues of this decade and a major sustainability cornerstone. In the case of interdependent CI systems, resilience depends on decisions and actions made by numerous public and private stakeholders. Ensuring the resilience of such complex socio-technical systems now hugely relies on inter-organizational capabilities within the network of stakeholders (infrastructure operators, civil protection, responders, etc.).

CIR involves various stakeholders from governmental and private organizations, groups, and individuals who are both affected by and contributing to the issue. Although no single stakeholder has enough authority, knowledge, or resources to remedy it alone (Trucco & Petrenj, 2017), governments retain formal responsibility for ensuring national progress and public well-being, which can be seriously impacted by CI disruptions. In a setup where information and

resources are distributed, governments must bring together networks of stakeholders to jointly analyze problems and find effective solutions, which is a major challenge (Crosby, 2010).

Governing, in general, is aimed at creating control, coordination, and collective action. However, in multi-stakeholder environments (public and private), with dispersed power, ‘ill-structured problems’, uncertainty, and complex interdependencies, it has become increasingly challenging (Ansell et al., 2017; Klijn & Koppenjan, 2016). Given the interdependent, cross-border nature of relationships between CI operations and the essential services they provide, EU Commission calls for a coordinated approach by the Member States as the way forward to strengthen the resilience of CI (CER Directive - EU, 2022). CIR, therefore, relies on the capacity to manage groups of stakeholders, where common hierarchical frameworks do not work, while there are still no clear answers on how to do it effectively. Public-Private Collaborations (PPCs) are currently the most prominent approach for building CI resilience adopted worldwide, but still face many obstacles and challenges.

This paper aims to evaluate how the Decentralized Autonomous Organization (DAO) paradigm (Wang et al., 2019) can enhance governance, decision-making, and resource management in cross-organizational collaboration for CIR. By comparing traditional governance models with DAO, the study assesses the strengths and limitations of different network governance approaches and their suitability to address the challenges of PPCs in CIR.

The paper's structure is as follows. Section 2 discusses the importance of an inter-organizational approach in CIR and presents different network governance models for implementing PPCs. Section 3 covers DAOs' key features and challenges. Section 4 explores how DAOs can help address challenges in cross-organizational collaboration for CIR. The final section summarizes the conclusions.

2. The Relevance of Inter-organizational Collaboration in CIR:

Public-Private Collaborations (PPCs) have emerged as a major governance and financial model in CIR. Even though PPCs carry huge potential, they are still facing many challenges in their establishment and management; mainly due to the lack of mechanisms for coordinating actions, reluctance to exchange sensitive information, a possibility for partners to act out of self-interest, ineffective governance, and inadequate financial support (Ampratwum et al., 2023).

PPCs for CIR are cooperative networks of legally autonomous organizations striving to attain both individual and collective objectives. Although hierarchy and control are unsuitable in voluntary collaborations, some governance is required to secure participant commitment, address conflicts,

and optimize resource utilization. Kenis and Provan (2009) identified three basic forms of network governance (Figure 1). They emphasize the critical role of network governance forms measured by network effectiveness – i.e. the collective (network-level) accomplishments and benefits that are unachievable by individual organizations acting independently. Along a similar line, Knodt et al. (2021) distinguish three types of coordination in CIR network governance:

- **Political leadership coordination** - the leading public actor takes unidirectional actions towards other actors, mainly by circulating information and requesting needed information.
- **Mutual exchange coordination** - private actors play an active role through ad-hoc bi-directional exchange with public actors, but still dominated by the public actor.
- **Positive coordination** - joint action based on deliberation, where consensus is reached by reasoning and mutual justification through regular coordination efforts among actors to establish trust and commitment.

2.1 Meta-governance

Alternative forms of inter-organizational network governance in CIR also consider meta-governance approaches, as an indirect form of governance, exercised by influencing the processes of actors' self-governance through coordination (Klijn & Edelenbos, 2007). Meta-governance is the practice of governing the process of governance itself. It involves the creation and implementation of rules, norms, and procedures to guide and regulate the behavior of actors involved in governance.

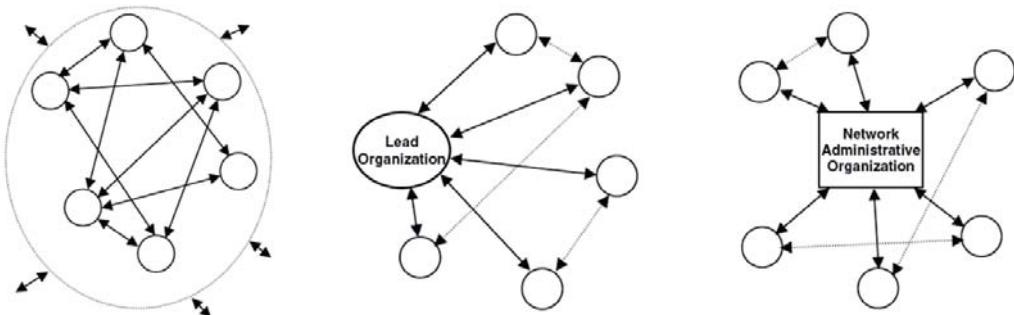


Fig. 1. Network governance approaches (adapted from Kenis and Provan, 2009): Shared governance network (left), Lead organization network (center), Network administrative organization network (right)

This includes establishing participation mechanisms; addressing transparency, accountability, participation, and decision-making processes; coordinating different modes of governance (i.e., hierarchy, network, and market governance); providing guidance and some level of control over various inter-organizational spaces (“*interactive arenas*” - Torfing et al. (2012)), such as collaborative arrangements, partnerships, networks and quasi-market arrangements (Gjaltema et al., 2020). An interactive arena implies the creation of a “governance space” where actors are given room to maneuver within regulative, normative, and discursive frames that are supportive of bottom-up problem-solving through self-organization (Torfing et al., 2012). Interactive arenas can be governed by administrative organizations, created voluntarily by members, or mandated in the process of network formation.

Meta-governance aims to enhance the effectiveness, legitimacy, and accountability of governance processes by establishing standards, principles, and guidelines for how governance should be conducted. It recognizes that the quality of governance is influenced not only by the decisions (actions) of those in power but also by the structures and processes that govern their behavior. Meta-governance also addresses the relationships between different governance actors, promoting a more inclusive and participatory approach. The key challenge is finding ways to “*facilitate, manage, and direct interactive governance arrangements without reverting to top-down command, and without undermining the self-regulatory capacity of networks, partnerships and quasi-markets.*” (Torfing et al., 2012; p.144).

There are two general meta-governance strategies (Figure 2): “hands-on” meta-governance, which entails active participation and management in interactive arenas, and “hands-off” strategies that are exercised at a distance and govern the network by means of network framing and network design (Sørensen et al., 2023). Ultimately, the aim is to create a more effective and accountable system of governance that can address the complex challenges facing our world today where traditional approaches are no longer viable.

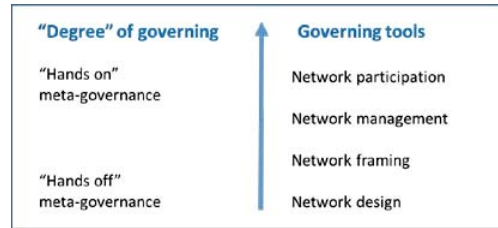


Fig. 2. Meta-governing activities (adapted from Sørensen et al., 2023)

The understanding of “organization” in the context of interactive arenas is different from the traditional meaning of the term in the sense that we must recognize ‘organizations-as-actors’ (Ahrne and Brunsson, 2011) capable of interacting with other actors (Österberg and Qvist, 2022). Formal organizations are typically founded on the decisions around: membership, rules, hierarchy, monitoring, and sanctions (so-called “elements of organization”) (Ahrne and Brunsson, 2011). “Partial organization” does not require all elements of a complete organization to be present for a situation to be considered organization. Organizations outside formal organizations (inter-organizational spaces; interactive arenas) are an excellent opportunity to study meta-governance in action and understand how organizational structures are created and decisions made regarding various organizational elements (Österberg and Qvist, 2022).

3. Decentralized Autonomous Organizations: key features and challenges

The use of blockchain technologies to facilitate governance processes is already attracting the attention of researchers (Ølnes et al., 2017) and practitioners (e.g. BLING project; TOKEN project). The distinctive characteristics of blockchain technology and smart contracts have enabled new kinds of decentralized systems and new ways of governance and coordination in CIR (Petrenj and Trucco, 2022). The most relevant approach is the so-called Decentralized Autonomous Organization (DAO) – a new organizational form to tackle challenges, where:

- An 'Organization' represents a group of people or entities working in collaboration on a common goal or specific mission;

- 'Decentralized' means that the structure is flat (no hierarchies), participation is encouraged and decisions are made collectively;
- 'Autonomous' in the sense that it is self-governing, i.e. governance rules are programmed into blockchain-based smart contracts (SCs).

Simply said, a DAO is a blockchain-based system enabling groups to coordinate and self-govern themselves in a decentralized manner, collectively managing joint resources. It is an internet-native organizational model, which is collectively owned, operated, and managed by its members (Cointelegraph, 2022). A DAO is created with a specific mission where its members work in coordination according to a shared set of rules encoded on a blockchain. This creates a transparent and distributed governance, allowing all stakeholders to participate directly, and make decisions jointly. The management and operational rules of a DAO are encoded on blockchain in the form of smart contracts and can autonomously operate without centralized governance or third-party intervention. DAO is therefore promising to become an effective approach to dealing with multi-actor decision-making in uncertain and highly dynamic environments.

The major problem DAO solves is the so-called principal-agent problem faced in many traditional organizations. In generic terms, the principal-agent problem is a conflict in priorities between the owner of an asset (a principal) and the person to whom the control of the asset has been delegated (an agent) (Cointelegraph, 2022). It occurs when there is a separation between ownership (with the liability for losses) and control (Investopedia, 2023), and comes with the risk that an agent can be motivated and will act in a way that is not in the best collective interest.

In the CIR domain, it can be manifested in misaligned goals and priorities between interdependent organizations. For example, governments retain formal responsibility for ensuring public purposes such as economic development, public health and safety. The privatization of CI systems has led to significant improvements in business efficiency, but it has also led to the prioritization of profits above all else (Llyr, 2022) which can come at the cost of managing risk and resilience needed to ensure continuity and quality of essential services to the

public. Simply, one organization might accept a high level of risk that may turn into higher exposure or damage to other interdependent stakeholders. DAO addresses the principal-agent dilemma through community governance, which relies on stakeholders voluntarily joining and abiding by the DAO's rules. They do not need to place trust in any agents acting on their behalf but instead, collaborate with a group whose goals are aligned. DAO incentivizes members to act in good faith, as they have a stake in the network's success. Acting maliciously would be acting against their self-interest (Cointelegraph, 2022).

3.1. DAO structure and establishment

A Decentralized Autonomous Organization (DAO) is generally composed of the following essential elements (Fernández, 2022; Guo, 2022):

- **Constitution, or DAO organizational model**, which explains the purpose of DAO, what does the DAO govern, and how does the governance process work.
- **Community**, consisting of DAO participants, rules of the membership and community management. This aspect also considers how DAO members communicate and coordinate using web solutions.
- **Proposal Process** specifies a multi-step process for creating, gathering support for, and crafting governance proposals.
- **Voting** defines the voting mechanism including rules on how voting takes place.
- **Implementation** covers the aspect of how the decisions are implemented. There might be also fail-safe features or other meta-governance structures.

The first step in creating a functioning DAO, based on its initial concept, requires the creation of a minimal set of smart contracts (SCs) from the DAO's core operating systems (Ruane and McAfee, 2022). These pieces of code are the foundation of a DAO and are self-executed every time certain criteria have been met. So, making the rules and the SC's code right must be done correctly from the very inception, otherwise, the DAO will not work as intended. Even small errors or omissions can cause large repercussions and operational failures later on, which is admittedly less problematic in private blockchains compared to public ones, where it can cause critical vulnerabilities.

The DAO's rules, established through SCs, must successfully deal with the governance aspects, such as defining who can make proposals (prevent DAO from being overwhelmed with proposals) (Cointelegraph, 2022), defining how the proposals are approved, i.e. what is the minimal quorum, what is the voting system and how the majority is determined. These rules vary with the application domain. In public DAOs, there is a need to get funding so usually governance tokens (with voting rights) are sold to raise funds (Ruane and McAfee, 2022).

The final step is the DAO launch, which is its deployment on the blockchain. From that point on, the stakeholders take over control of the DAO and collectively decide on every aspect of its future development (Cointelegraph, 2022).

The DAO transparency is reflected in:

- Governance – SCs are open to all DAO members (to view their code), and are also subject to change proposals, meaning that the governance model can evolve. It implies that the governance rules can be changed, but only through the same mechanism as all the other decisions are made;
- Proposals – are visible by all the members making individual contributions recognized for bringing value to the joint goals;
- History – members can audit DAOs history since all the interactions are recorded on a blockchain, which is specifically important if there is a financial dimension in the DAO including monetary transactions.

3.2. Decision-making in DAO

The decision-making process is performed through proposals and voting, which makes DAO transparent to its members and ensures that everyone gets a say (Ruane and McAfee, 2022). In contrast to the hierarchical approaches, DAOs remove the layers of bureaucracy by adopting a simple structure where any stakeholder can make a proposal, and every stakeholder can vote on every decision. Initiatives (projects and priorities) are put before the DAO community in the form of proposals, and all the members can then vote on them. Proposals often trigger discussions and ideations around them on chosen communication platforms and can undergo revisions before being adopted (Ruane and McAfee, 2022). A proposal can be about DAO's operations, but also about

strategic or governance aspects ('governance of governance'). The common types of proposals (scopes of the decisions) are:

- Constitution Amendment – proposed modifications to the DAO constitution;
- Executable proposal – SC execution through the DAO's wallets;
- Social proposal – Modifications that do not need on-chain activity;

Several new governance models can be used by DAOs to manage their operations and decision-making processes:

- **Token-based governance:** In this model, the voting power and the decision-making authority are based on the number of tokens held by each member. Members can use their tokens to vote on proposals and decisions;
- **Reputation-based governance** bases decision-making authority on a member's reputation within the DAO community, earned through contributions to the network.
- **Hybrid governance** combines elements of both token-based and reputation-based governance. Members may have both voting power based on their token holdings and reputation-based authority depending on the quality of their contributions;
- **Quadratic voting governance** involves using a quadratic formula to determine voting power, which gives more weight to minority opinions. Members can use their voting power to support multiple proposals, but the weight of their vote decreases with each additional proposal;
- **Liquid democracy governance** allows members to delegate their voting power to others in the community, who can then vote on their behalf. This allows for more fluid decision-making and encourages greater participation.
- **Futarchy governance** involves using market mechanisms to determine the best course of action for the DAO. Members can place bets on the outcomes of proposed decisions (success or failure), and the proposal is only implemented if the market predicts it will be successful.
- **Holacracy governance:** In this model, DAO authority is distributed in the form of self-organizing teams or "circles", each with its

own purpose/function and decision-making authority related to that purpose. Circles create and update their own governance procedures. Holacracy also includes a set of core rules and principles that govern how circles interact with one another and ensure that decisions and activities are aligned and coordinated across circles.

These governance models can be combined or customized to fit the specific needs and context of the DAO and the preferences of its members.

3.3. DAOs and the real world

DAO is a structure that leverages technology to operationalize interactions and improve governance efficiency (its operational aspects). The social and political aspects of governance must also be considered and aligned.

DAO paradigm requires high education and participation, with complex governance models that demand time to be understood. Although the voting system is automated, each member must read proposals to make informed decisions. Hierarchies can still exist to ensure that qualified individuals make the right decisions, even under time constraints. However, high-profile members can gain an outsized influence on decision-making. Gathering information for informed decisions can be time-consuming, leading to reduced participation. In many cases, DAO members may not be interested in voting. For the vast majority of the DAOs running on public blockchains (99% of them), on average less than 0.5% of governance token holders actually participate in voting on proposals (Guo, 2022). This can lead to another possible bottleneck, which is the voting quorum, since without it no proposal will pass. The limitations related to the capacity of DAO members to engage in governance must be carefully considered and addressed.

DAO faces challenges in dealing with real-world connections that have not yet been fully addressed (Llyr, 2022). As an emergent form of organization, DAO is not yet legally recognized, which creates issues when interacting with traditional legal entities, such as signing legally binding contracts (Ruane and McAfee, 2022). If the DAO purchases a physical asset that asset will need a custodian, insurance and a tax accountant (Llyr, 2022). Most DAOs are called ownership-free organizations, which means that all assets

that are inside the DAO are jointly owned (Dubnevych, 2022). DAO members might be exposed to liabilities and duties that could put their other assets at risk, which might make them reluctant to join or support a DAO.

4. Discussion

Simple decentralization, meaning the dispersion of decision-making autonomy, can undermine the operational safety of hierarchical organizations due to a lack of coordination, missing expertise at a lower level, limited oversight, and inconsistent standards (Monteiro et al., 2020). Such delegation of decision-making authority can create a principal-agent problem where branches, teams, or individuals might prioritize local business pressures over the safety goals of the entire organization. Those issues can be addressed by a more centralized operational safety function, but still at the cost of decision-making efficiency (Monteiro et al., 2020). A DAO, as an alternative approach, could address the same issues by: incorporating safety goals in local decision-making (e.g. by involving a safety expert); implementing SCs that enforce safety standards; transparency; community feedback and oversight.

In general, DAO fosters a proposal meritocracy and distributes the decision-making power in favor of the wisdom of the stakeholders. One of the primary advantages of a decentralized organization is the ability to empower both subject matter experts and people closest to stakeholders.

Preparedness and responsiveness are crucial in CIR programs, and the concept of moving decision rights closer to the front-line personnel is not a new one (Alberts and Hayes, 2003). In complex and high-risk environments (High Reliability Organization – HRO; Roberts, 1990), information and decisions need to move quickly to enhance agility and adaptability. In PPCs, the people that are most knowledgeable about process and system interdependencies can take initiatives toward shared goals, addressing issues quickly and making the decentralized organization agile. DAO's non-hierarchical structure encourages participation where everyone gets a say, in the sense that anybody can make proposals and have them voted on by the members. This can lead to more informed decisions, improved management of limited resources, and, overall, more efficient collaborations, which aim to outperform

hierarchies. However, flat structures with numerous participants with different interests and expertise can be a burden to efficiency. The classical DAO approach of engaging and relying on too many people for every single decision would lead to extremely slow decision-making (Mueller, 2022) eventually diminishing the benefits of decentralization. This questions if DAO would be more efficient than a more centralized (hierarchical) organization. The very aspect that makes a DAO nimble and autonomous also creates challenges that will need to be addressed in order for DAO to realize its full power (Lyr, 2022).

There are several ways to address the issues of participation, capacities, and operational efficiency in decision-making in PPCs. Firstly, a mix of centralized and decentralized decision-making can be applied based on tasks and needs. The level of decentralization can depend on the specific goal, e.g. with strategic decisions being made at the organizational level of PPCs and operational decisions at lower levels. Secondly, DAO is adaptable, meaning they can begin with a more centralized structure and transition to a more democratic, decentralized form, or vice versa (Arca, 2022), through constitutional amendments (governance proposals). As a result, the degree of decentralization in a DAO may vary based on its goals and priorities. Thirdly, members of hierarchical organizations run on permissions (approval from a superior) whereas DAO runs on constraints – meaning one can do anything that is not disallowed, which is achieved by consent (coming to a mutual agreement between peers) (Mueller, 2022). Since getting consent from a large group of people is troublesome, existing DAOs are often segmented, which tends to increase organizational effectiveness (Arca, 2022). These are small autonomous units of members, such as working groups, committees, subcommittees, circles, or pods (Mueller, 2022). The units are connected and can have sub-units, they are flexible and formed through proposals and voting by members. Leaders in specific domains naturally emerge based on their competencies, and they can be nominated, elected, or voted out by the community (Fernández, 2022). The DAO structure allows for multiple sub-DAOs within an organization, enabling specialists to work within their domains while contributing to the overall productivity (Arca, 2022). Structures of

self-managed organizations thus organize people around the work to be done, instead of organizing the work around the people. In the domain of inter-organizational collaborations for CIR, DAO could enable the setting up of a temporary inter-institutional organization, where people come from different actors and are grouped in teams according to the mission objectives and required activities. Smart contracts make it certain that everyone involved in the temporary organization will work according to the responsibilities and rules of his/her own organization of origin in a transparent way. For example, a DAO can be organized by specific domains, or for specific resilience-building tasks (as task forces).

Another mechanism aimed to increase operational efficiency is the delegated authority model (liquid democracy governance), in which a member delegates his decision-making rights to a qualified leader in a specific domain, to make key decisions more efficiently and still in a transparent manner (Mart and Dempsey, 2021). Constrained delegation can set trust boundaries and limit the scope of delegation while allowing experts to perform their jobs autonomously, while still being held accountable to the DAO.

The transparency of decisions, initiatives, actions, and contributions can significantly increase trust and willingness to share information in PPCs. The funding of PPCs in CIR, which is another major challenge, depends on the ability of partners to align their objectives and join their individual capabilities. DAO can provide an efficient approach to raising funds for specific goals (e.g. government grants, private sector investments, and joint funding) and ensure that is used effectively and efficiently.

5. Conclusions

The DAO paradigm opens plenty of new organizational governance and management capabilities that must be carefully analyzed when considering options for its implementation. In the context of PPCs around CIR, DAO could allow for enhanced collaboration between the public and private sector stakeholders. This could help ensure that CIR efforts are coordinated effectively and that decisions are made in a decentralized and democratic manner. More specifically, DAO could: facilitate transparent and secure inter-organizational communication and decision-making; allow for an effective allocation of

resources to different initiatives aimed at improving CIR and monitoring their progress; incentivize stakeholder participation in CIR efforts and reward participants for their contributions; institutionalize collaboration in the sense that it does not rely on individuals. DAO also supports the principle of subsidiarity, so that decisions and actions related to CIR could be made at the local level, under higher-level frameworks, and tailored to the specific needs of local stakeholders.

In the long-term DAO can allow for quicker prototyping and experimenting with social and organizational aspects of governance, which are lagging with respect to the advancements of digital tools and technologies. DAO is still in an experimental phase but might bring lots of value to group-level endeavors in the future.

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