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Advancing Decentralized Autonomous Organizations in Blockchain-Based Systems: Taxonomy, Large-Scale Evaluation, and Network Insights

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List of Abbreviations

Assets under management (AUM)

Augmented Bonding Curve (ABC)

Bitcoin Improvement Protocols (BIPs)

Blockchains (BC)

Central Exchange (CEX)

Decentral Organizations (Dos)

Decentralized Apps (dApps)

Decentralized Autonomous Corporations (DACs)

Decentralized Autonomous Organizations (DAOs)

Decentralized Exchange (DEX)

Decentralized Finance (DeFi)

Decentralized Governance (DeGov)

Design Feature (DF)

Design Principle (DP)

Design Requirement (DR)

Enterprise Resource Planning (ERP)

Ethereum Improvement Protocols (EIPs)

Ethereum Virtual Machine (EVM)

Food and Drug Administration (FDA)

Information System (IS)

Initial Coin Offerings (ICOs)

Initial Decentralized Offerings (IDOs)

Initial Exchange Offerings (IEOs)

Internet of Things (IoT)

Large Language Models (LLMs)

Latent Dirichlet Allocation (LDA)

Non-Fungible Token (NFT)

Pay to Earn (P2E)

Process Quality Review (PQR)

Requests for Comments (RFCs)

Technology-Organization-Environment (TOE)

Total Value Locked (TVL)

US-Dollar (USD)

Unique System Identifier (USID)

Voting Power (VP)

Abstract

In an effort to decoding Decentralized Autonomous Organizations (DAOs) from an academic viewpoint, this thesis advances the understanding of DAOs with several contributions to theory and practise. The contributions are reached by six essays that each expand a subfield in DAO research. The first essay presents a novel taxonomy of DAOs that helps researchers understand the type of DAO they are currently looking and separating their dataset by type of DAO to get clearer results about for example performance or success of a DAO. The taxonomy is established using quantitative data and a design science method. The second essay investigates the scoring methodologies that practitioners use for evaluating DAOs. The study uses and qualitative approach analysing the scoring methodology of three major scoring platforms and combining their similarities and differences. This helps industries such as venture capital firms to develop their own scoring methodologies for evaluating DAOs to make better investment decisions when investing into DAOs. The third essay constructs an information system to bridge the communication gap between customers and manufacturers in a recall process. This system sets an example for the capabilities of public blockchains and presents a use-case other than decentralized finance and supply chain management. Information systems like this will be governed by DAOs in the future and current research on DAOs must be aware of the requirements of future DAOs. In the fourth essay, this thesis investigates decentralization and network properties of DAOs using a large-scale making several findings. First, the 90-9-1 rules previously applicable to online communities also applies to DAOs. Second, showing an unequal distribution of voting power using a deciding voter analysis. Third, it validates the scale-free network properties by fitting a power-law function to the degree distribution of DAO memberships and proposal participation suggesting the existence of influential nodes within the network. The fifth essay serves as a research agenda for future research into DAOs. Using a literature review approach, it presents the evolution of DAO definitions, summarizes and comments existing research and presents common pitfalls researching DAO. Furthermore, it investigates the actual data available to researchers and makes concrete recommendations for dealing with it for research. The sixth and last essay investigates data augmentation of proposal data of DAOs using large language models (LLMs). In this essay, categories and their definitions for DAO proposals, a prompt usable with GPT-4, and framework parameters are designed with an iterative design science approach with the goal to automatically classifying DAO proposals. This highly reproducible research helps researchers investigating governance in DAOs to for example measure effort, cost or performance governance to separate different types of proposals. Overall, the thesis contributes to the academic understanding of DAOs by providing a taxonomy of DAOs, a categorization of DAO proposals, insights into decentralization and network properties, and a research agenda for DAOs, advancing the field both from a practical and theoretical perspective.

Kurzfassung (German Abstract)

In dem Bemühen, Dezentrale Autonome Organisationen (DAOs) aus akademischer Sicht zu entschlüsseln, trägt diese Arbeit mit mehreren Beiträgen zu Theorie und Praxis zum Verständnis von DAOs bei. Die Beiträge werden in sechs Aufsätzen geleistet, die jeweils ein Teilgebiet der DAO-Forschung erweitern. Der erste Aufsatz stellt eine neuartige Taxonomie von DAOs vor, die Forschern hilft, die Art von DAOs zu verstehen, die sie gerade untersuchen, und ihren Datensatz nach DAO-Typ zu unterteilen, um klarere Ergebnisse über beispielsweise die Leistung oder den Erfolg einer DAO zu erhalten. Die Taxonomie wird mit Hilfe quantitativer Daten und einer designwissenschaftlichen Methode erstellt. Der zweite Aufsatz untersucht die Bewertungsmethoden, die Praktiker zur Evaluierung von DAOs verwenden. Die Studie verwendet einen qualitativen Ansatz, der die Bewertungsmethoden von drei großen Bewertungsplattformen analysiert und ihre Gemeinsamkeiten und Unterschiede kombiniert. Dies hilft Branchen wie z. B. Risikokapitalfirmen, ihre eigenen Bewertungsmethoden für die Bewertung von DAOs zu entwickeln, um bessere Investitionsentscheidungen bei Investitionen in DAOs zu treffen. Der dritte Aufsatz konstruiert ein Informationssystem zur Überbrückung der Kommunikationslücke zwischen Kunden und Herstellern in einem Rückrufverfahren. Dieses System ist ein Beispiel für die Fähigkeiten von öffentlichen Blockchains und stellt einen anderen Anwendungsfall als dezentrales Finanz- und Lieferkettenmanagement dar. Informationssysteme wie dieses werden in Zukunft von DAOs verwaltet werden, und die aktuelle Forschung zu DAOs muss sich der Anforderungen zukünftiger DAOs bewusst sein. Im vierten Aufsatz untersucht diese Arbeit die Dezentralisierungs- und Netzwerkeigenschaften von DAOs anhand eines groß angelegten Projekts und kommt dabei zu mehreren Ergebnissen. Erstens: Die 90-9-1-Regel, die bisher für Online-Communities galt, gilt auch für DAOs. Zweitens zeigt sie eine ungleiche Verteilung der Stimmkraft anhand einer Analyse der entscheidenden Wähler. Drittens werden die Eigenschaften eines skalenfreien Netzwerks bestätigt, indem eine Power-Law-Funktion an die Gradverteilung der DAO-Mitgliedschaften und der Beteiligung an Vorschlägen angepasst wird, was auf die Existenz einflussreicher Knoten innerhalb des Netzwerks hindeutet. Der fünfte Aufsatz dient als Forschungsagenda für zukünftige Forschungen zu DAOs. Anhand eines Literaturüberblicks wird die Entwicklung von DAO-Definitionen dargestellt, bestehende Forschungsarbeiten werden zusammengefasst und kommentiert und häufige Fallstricke bei der Erforschung von DAO aufgezeigt. Darüber hinaus wird untersucht, welche Daten den Forschern tatsächlich zur Verfügung stehen, und es werden konkrete Empfehlungen für den Umgang mit diesen Daten für die Forschung gegeben. Der sechste und letzte Aufsatz untersucht die Datenerweiterung von Vorschlagsdaten von DAOs unter Verwendung großer Sprachmodelle (LLMs). In diesem Aufsatz werden Kategorien und ihre Definitionen für DAO-Vorschläge, ein mit GPT-4 verwendbarer Prompt und Rahmenparameter mit einem iterativen Design Science-Ansatz entwickelt, um DAO-Vorschläge automatisch zu klassifizieren. Diese hochgradig reproduzierbare Forschung hilft Forschern, die Governance in DAOs untersuchen, um zum Beispiel Aufwand, Kosten oder Performance Governance zu messen und verschiedene Arten von Vorschlägen zu unterscheiden. Insgesamt trägt die Arbeit zum akademischen Verständnis von DAOs bei, indem sie eine Taxonomie von DAOs, eine Kategorisierung von DAO-Vorschlägen, Einblicke in Dezentralisierungs- und Netzwerkeigenschaften sowie eine Forschungsagenda für DAOs liefert und das Feld sowohl aus praktischer als auch aus theoretischer Sicht voranbringt.

1 Introduction[1]

Decentralized Autonomous Organizations (DAOs) have emerged from blockchain-based systems, especially bitcoin. While Bitcoin could be seen as the first DAO (Buterin, 2014; Hsieh et al., 2018), the first discussion of a practical DAO only started years later with the whitepaper of Jentzsch (2016), which implemented the first DAO on Ethereum (Buterin, 2013). While "The DAO" ultimately collapsed (DuPont, 2017), a new generation of DAOs emerged soon after, with MakerDAO[2] governing the stablecoin DAI using the governance token MKR completely on-chain, while MolochDAO[3] strives to fund infrastructure projects in Ethereum in a decentralized way.

Although DAOs do not have a robust academic definition yet, they can be defined as information systems (IS) with different functions that either mediate interactions between humans and blockchains or operate as a completely autonomous system that enables storage of value, transaction of value, governance mechanisms, and autonomous execution of governance decisions each in a decentralized environment (Hassan & Filippi, 2021; Rikken et al., 2023; Schillig, 2021; Wang et al., 2019).

DAOs are used to automate governance processes on blockchain-based applications using online voting mechanisms known as proposals, utilizing token-based voting. (Fan et al., 2023; Rikken et al., 2023). They can have very different structures and purposes depending on their goal. For example, "The LAO"[4] is a member-directed venture capital fund that allows members to pool capital, invest in projects and share proceeds from investments. "The LAO" has backed over 130 projects across the blockchain-ecosystem with more than 1b$ invested (crunchbase,

[1] This chapter is based on the motivation of the six essays of the thesis.
[2] https://makerdao.com/en/
[3] https://molochdao.com/
[4] https://thelao.io/about

2023). BanklessDAO aims to on-board more people about decentralized technologies by investing into education about blockchain, DeFi, NFTs and every technology related to decentralization (Messari, 2023a). Developer DAO also aims to accelerate the education about decentralization but does so by actively supporting builders in the web3 space (Messari, 2023b).

DAOs have primarily been seen as organizations by scholars in the past (Hassan & Filippi, 2021; Wright, 2021), but can also be seen as online communities, as the properties DAOs build on mainly stem from those known in the literature of online communities. According to Preece (2000), online communities consist of people interacting socially, that share a common purpose, while following policies that guide interactions, and utilize computer systems to support and mediate interactions. These properties can be mapped to DAOs, where a shared purpose and policies are defined in governance, and the blockchain serves as the computer system supporting the interactions.

Despite the promise of decentralization in DAOs, first empirical studies have shown, that most DAOs are not very decentralized, with most voting power concentrated at few individuals (Feichtinger et al., 2023; Fritsch et al., 2023).

Taking a step back, the DAOs analyzed in this thesis are built on public ledgers, more specifically public blockchains. In general, DAOs are blockchain agnostic and can in theory be built on any ledger. A ledger is a decentralized storage that uses a consensus mechanism to verify appends, facilitated by transactions to itself, while a blockchain not only uses the consensus mechanism but also puts each transaction into a block instead of directly letting the transaction modify the state (Tasca et al., 2016). These ledgers can be public or private, where on a public ledger anyone can join the network by spinning up a new node and a private one requires an invitation, or more specifically, an authorized cryptographic key (Tasca et al., 2016).

There are currently many competing public blockchains where DAOs are being built. However, currently, almost all DAOs are primarily on Ethereum Virtual Machine (EVM)-based Blockchains or solely on Ethereum. While the first blockchain is bitcoin, the first blockchain that allowed for complex computations, so called smart contracts, computed within the blockchain is Ethereum (Buterin, 2013). Smart contracts create the base for more complex structures on blockchains. One of these structures are tokens. The Bitcoin network for example uses the cryptocurrency Bitcoin to pay for transaction costs and mining rewards and the Ethereum network uses the cryptocurrency Ethereum to pay for transactions, but more specifically computation within the Ethereum Virtual Machine (EVM). The EVM allows programmers to execute smart contracts in the Ethereum network. One possible implementation of a smart contract is the ERC20 standard (Vogelsteller & Buterin, 2015), it describes a contract that issues a new Token and allows the transfer and usage of it. Other examples of token contracts are ERC721 (Entriken et al., 2018) for Non-Fungible Tokens (NFTs) and ERC1155 (Radomski et al., 2018), which is a multi-token standard for fungible tokens and NFTs. With this approach, a single blockchain can have many different tokens, where the supply is determined by the entity deploying the contract and not only the currency used to pay for transactions.

Using these custom tokens, specialized smart contracts can be designed that act as an application on the blockchain, so called decentralized applications (dApps), as for example Uniswap[5] and Sushi[6] that exchange different tokens, or Aave[7] and compound[8] that facilitate lending of cryptocurrencies.

[5] https://uniswap.org/
[6] https://www.sushi.com/
[7] https://aave.com/
[8] https://compound.finance/

With DAOs, the goal is, that these applications are governed by the holders of the respective governance tokens for example $UNI for Uniswap, such that those that have used the application early or invested their money into it, can decide what happens to the protocol using proposals and token-based voting.

This goes in line with the shift from web2 to web3. While web2 is about centralized platforms such as twitter and facebook actively building a walled garden (Srinivasan, 2019), and centralizing social activity inside a single platform in the winner-take-all market of a closed communications platform (Srinivasan, 2019), the goal of web3 is to decentralize the platforms and their governance (Wood, 2018).

1.1 Motivation and Research Questions

The sheer amount of different DAOs with different goals calls for the need of a taxonomy for better understanding specific dimensions and characteristics of DAOs. While Wright (2021) has offered an intuitive taxonomy of DAOs that describes DAOs as either Algorithmic DAOs or Participatory DAOs, a more sophisticated data-driven taxonomy is needed to help researchers build future models that for example predict or measure the performance of a certain DAO type. A taxonomy based on data offers increased reliability and precision, and is applicable to a wider range of DAO, making it more effective for the systematic organization of future research in the field of DAOs. Therefore, we ask the following research question:

- RQ (Essay I): Which common characteristics do DAOs share, and which clusters of DAOs can be created, based on their characteristics?

DAOs use proposals for performing their governance. Each proposal has a topic to perform an action as a DAO and can be voted on mostly using token-based voting. Proposals can have different phases such as pre-discussions, forum discussions, voting and implementation. With proposals, any action can be performed as a DAO and all aspects of a DAO can be changed, such as allocating funds, changing risk parameters of a Decentralized Finance (DeFi) application, upgrading the protocol, changing the rules for governance, or engaging in partnerships with other DAOs or companies. This huge variance of different types of proposals makes it hard for a researcher to analyze the impact and effectiveness of proposals as a whole, as there could be many less relevant proposals such as a minor adjustment of a parameter from a DeFi protocol and only a few very impactful proposals that for example change the core protocol in the governance of a DAO. Tackling this problem, the thesis asks the following research question:

- RQ (Essay VI): What categories of DAO proposals exist, what is their prevalence, and how can researchers and practitioners automatically classify them?

The above-mentioned assessment of DAOs is relevant for a range of practitioners that, for example invest or participate in DAOs, but also for academics that want to evaluate DAOs. To make an informed decision or evaluation, a rigid scoring methodology is necessary so that the decision or evaluation is based on facts and not on intuition. For this, practitioners and academics have already many scoring methodologies for DAOs, such as Zizi (2021), DeepDAO (2023), Adjovu (2021), Axelsen (2022), Prime Ratings (2023), Baserank (2023), DeFi Safety (2023), DAOMeter (2023), Regner (2022), Mattila et al. (2022). However, there has been no investigation into the specifics of current scoring methods for DAOs. Thus, this thesis proposes the following research question:

- RQ (Essay II): What similarities and differences in their scoring methodologies are shared by DAO rating platforms?

These three research questions aim to both extend the understanding of DAOs and formalize implicit knowledge on attributes of DAOs to build better evaluation methodologies in the future.

DAOs cannot only be used to govern a DeFi Protocol but can in theory be used as a governing entity for any blockchain-based system. As described earlier, DAOs are already used to govern crowdfunding, stablecoins, online communities or collections of digital assets. Therefore, this thesis argues that there is nothing that would prevent a DAO from governing a supply chain application. For this purpose, the following research question is asked:

- RQ (Essay III): How can an information system be utilized to improve recall communication between customers and manufacturers in a recall process to establish a co-value creation approach?

Using this information system, new requirements for future DAOs can be derived.

Having looked at properties of DAOs, their proposals, scoring methodologies and future requirements, a study of the inner workings of DAOs remains. While this thesis sees DAOs more like online communities and less like organizations as stated previously, techniques for investigating online communities are required for an Analysis.
In the initial stages of researching online communities, there was uncertainty about whether established methods used for analyzing offline communities, like network analysis, could be applied (Preece, 2000), it subsequently became evident that they are (Easley & Kleinberg, 2019; Panzarasa et al., 2009; Yang et al., 2011). Therefore, an analysis into the network properties (Barabasi & Albert, 1999; Barabási, 2009) of DAOs and participation inequality in online communities (Nielsen, 2006) can be employed. Goldberg and Schär (2023), Feichtinger et al. (2023) and Fritsch et al. (2023) have already looked at the distribution of voting power and

decentralization in DAOs. Augmenting their method and findings, the thesis asks the research questions:

- RQ (Essay IV): Can participation inequality present in DAOs be shown for DAOs?
- RQ (Essay IV): What is the extent of dominance exerted by deciding voters in the governance process?
- RQ (Essay IV): Do DAOs exhibit the characteristics of scale-free networks?
- RQ (Essay IV): How does the connectivity of a node in the network influence the diffusion of information?

Last, a goal of this thesis is, to provide new researchers with tools to conduct research into DAOs without starting from scratch. For this, a rigid and complete literature review is needed, to first provide the background on DAOs, their definitions and recent work as well as a review of platforms that record data for DAOs created by practitioners. Last, current research gaps are not yet well described. Therefore, the following research questions are asked:

- RQ (Essay VI): How has DAO research and the definition of DAOs evolved in the past years?
- RQ (Essay VI): What are common pitfalls for researchers working with Data for DAOs and where can this data be gathered from?
- RQ (Essay VI): What are related fields that can be combined with current DAO research to provide new perspectives for future research?

1.2 Research Methodology

To answer the research questions, a mixed method approach is used, where for each research question, a fitting methodology is chosen. Essay I uses a qualitative approach following Nickerson et al. (2013), semi-structured expert interviews (Finkbeiner, 2017), agglomerative clustering using the Wards method (Ward, 1963) and cluster measures (Berkhin, 2006; Davies & Bouldin, 1979; Dunn, 1974; Pedregosa et al., 2011). Essay II employs a literature review (Kitchenham, 2004) and content analysis (Krippendorff, 2019). Essay III performs a design science research method according to Möller et al. (2020) and evaluates it based on the questionnaire of Iivari et al. (2021). Essay IV draws theory from Nielsen (2006) investigating participation inequality and Barabási (2009) for network theory. Essay V uses and integrative literature review (Torraco, 2005) and Essay VI executes the design science research method according to Peffers et al. (2007) and Nickerson et al. (2013), employing GPT-4 (OpenAI et al., 2023) for automatic classification.

1.3 Structure

This thesis is divided into six distinct essays that each have their own introduction, methodology, application of the of the methodology and results. Before each essay, the current publication or review status is declared as well as a list of all venues the work has been presented. In addition, references for each essay are available after each essay. After the essays, the most important contributions are summarized, and an overall conclusion is drawn.

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2 Essay I: A Taxonomy of Decentralized Autonomous Organizations

Abstract

Decentralized Autonomous Organizations (DAOs) are trustless organizations that automate transactions, operations, and decisions without a trusted third party (Wang et al. 2019). So far, this research area is missing a taxonomy that investigates the different dimensions and characteristics of DAOs and the many different forms they can take. This paper addresses this research gap by creating a data-driven taxonomy analyzing 72 DAOs. In doing so, we identify the three main categories treasury, community, and governance, seven sub-categories, 20 dimensions, and 53 characteristics. In addition, we provide dimensions with inadmissible characteristics DAOs cannot take, as well as dimensions used to assess DAOs. The results of our agglomerative clustering are five distinct DAO types: On-chain product and service DAOs, off-chain product and service DAOs with community focus or with investor focus, investment-focused DAOs, and networking-focused community DAOs.

Keywords: Decentralized Autonomous Organizations; Taxonomy; Blockchain

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2.1 Introduction

Decentralized autonomous organizations (DAOs) are an increasingly important topic in information systems, organizational sciences, and practice. The total market capitalization of the top ten DAOs now exceeds 8 billion dollars, with BitDAO alone having a market capitalization of 2.2 billion dollars (DeepDAO 2022). The increase in market capitalization was mainly fueled by the interest of institutional investors, who have been starting to invest in DAOs lately. The famous venture capital firm, Andressen Horrowitz (a16z), has invested in DAOs, such as Syndicate (Yahya 2021b), Friends With Benefits (Carra Wu and Chris Dixon 2021), BreederDAO (BreederDAO 2022), and PleasrDAO (Yahya 2021a).

Due to the growing interest in information systems, scholars have recently called for the classification of perceived DAOs particularly those closely related to Decentral Organizations (Dos) (Rikken et al. 2021); for which our taxonomy lays the foundation. Previous research has predominantly studied DAOs from a descriptive, theoretical perspective; or else it has analyzed a small number of DAOs or specific events, like the DAO hack (Dhillon et al. 2017) and governance at a general level (Rikken et al. 2021). Research so far leaves behind a need for research into various types of DAOs and for clarification of relevant definitions and characteristics (Rikken et al. 2021).

Wright (2021) has offered an intuitive taxonomy for DAOs, which describes two distinct organizational designs: Algorithmic DAOs and Participatory DAOs. While we agree with the intuitive taxonomy of Wright (2021), a more sophisticated, comprehensive, data-driven taxonomy that looks at the specific characteristics of DAOs offers advantages for further research into DAOs. A more comprehensive taxonomy is necessary, as only a data-driven taxonomy that looks at these characteristics allows researchers to build solid models. These models are used to predict the performance of DAOs or to provide information about the trustworthiness of DAOs in terms of real-world DAO development. A data-driven type of taxonomy is more reliable, precise and applies to more DAOs. Thus, it is more conducive to the systematization of future DAO research.

Therefore, we formulate our primary research question as follows:

RQ: Which common characteristics do DAOs share, and which clusters of DAOs can be created, based on their characteristics?

Following Rikken et al. (2021), we define DAOs as "a system in which storage and transaction of value and notary (voting) functions can be designed, organized, recorded, and archived; and where data and actions are recorded and autonomously executed in a decentralized way". Furthermore, we extend the definition by requiring an explicit notary (voting) process for each DAO. An explicit notary (voting) requires a process that is not ad hoc and leaves space and time for discussion. In contrast, an implicit voting process allows eligible voters to vote without any process and discussion. Additionally, we impose a limitation on our DAO dataset insofar as a DAO cannot be a group of people with access to a multi-signature wallet without any other tools; where this wallet holds funds without the existence of any formal voting procedure. Lastly, we require a DAO to have an ecosystem where contributors are rewarded for their work. We implement these three limitations as we focus on organizations that are mature and not in a transition or setup phase where certain procedures are not fully implemented yet.

In the next section, we briefly explore the foundations and present work related to our research. Next, we present our methodology by introducing meta-characteristic and ending conditions and simultaneously describe our methods for data collection, iterations, and evaluation. We then present the resulting taxonomy and explain all of the relevant dimensions in detail. After that, we apply our taxonomy, using clustering techniques to identify categories of DAOs. Finally, we discuss the direct result of this work and explore future research opportunities.

2.2 Foundations and Related Work

In this section, we explain first the core concept of DAOs. We present two different definitions of DAOs and refine our definition for this work, based on an existing definition for DAOs. Then we explain the need for taxonomies and how researchers can use them in closely related fields. Last, we state the main reason for this research and the research gap.

The core concept of DAOs is that a virtual entity with a particular set of members, who are shareholders, that have the right to vote, spend the entity's funds, and modify its code. This concept allows members to decide the organization's future and its assets collectively, using smart contracts (Buterin 2013). Furthermore, there have been other definitions of DAOs. For example, Hsieh et al. (2018) define DAOs "as non-hierarchical organizations that perform and record routine tasks on a peer-to-peer, cryptographically secure, public network, and rely on the voluntary contributions of their internal stakeholders to operate, manage, and evolve the organization through a democratic consultation process." However, with this definition, blockchain-based systems like Bitcoin are categorized as DAOs (Buterin 2014; Hsieh et al. 2018). Also, Rikken et al. (2021) maps a wide range of DAO definitions and characteristics, in order to derive a comprehensive definition therefrom.

In recent years, multiple scholars have researched DAOs, which has led to a fragmented understanding of DAOs. For example, Wang et al. (2019) brings up a reference model for DAOs. Hsieh et al. (2018) states the history of DAOs and developments starting with Bitcoin. Hassan and Filippi (2021) discuss the origin and evolution of the term *DAO*, as well as relevant definitions and open questions; while El Faqir et al. (2020) showcase DAO tools.

There have been various studies of taxonomies in closely related fields, such as blockchain-based-systems (Glaser 2017; Glaser and Bezzenberger 2015); smart contracts (Hofmann et al. 2021); ICOs – a blockchain-enabled form of crowdfunding (Fridgen et al. 2018); and crowdfunding (Haas et al. 2014). Still, to the best of our knowledge, nobody has ever offered a systematic taxonomy of DAOs; identifying the full spectrum of their organizational primary and secondary functional building blocks, such as governance and reward mechanisms. This research is highly required because further studies on DAOs need a profound taxonomy as a foundation. For example, there have – so far – not been any quantitative studies looking at how these organization and governance structures relate to DAO performance both during, and after, the launch of a DAO. However, Zhao et al. 2022 look at how strategic and operational voting tasks influence product quality. They conclude that the number of operational voting tasks negatively affects product quality. Furthermore, they conclude that strategic voting tasks influence product quality when taken as a proportion of the total workload and not analyzed directly.

Tsoukalas and Falk 2020 investigate the effectiveness of decentralized platforms witch use token-weighted-voting and crowdsource information from users. They find that token-weighting generally discourages truthful voting. Additionally, they find that „Platform accuracy decreases with the number of truthful users and the dispersion in their token holdings".

While these studies have enhanced our understanding of certain DAO dimensions, they so far have not looked at most dimensions of a DAO but merely at a smaller set of dimensions such as voting in a DAO.

A solid taxonomy, containing a synthesis of current knowledge regarding organizational design, governance, reward mechanisms, and launch paths, is needed to foster a shared understanding for future research. Our taxonomy builds on Rikken et al. (2021), who provide an in-depth study of DAOs by analyzing definitions, characteristics, and emerging developments.

2.3 Methodology

We follow an iterative, two-step approach that combines empirical, conceptual, and deductive research methods; this, in turn, develops a taxonomy that can be used to answer the research question and to lay a data-driven foundation for future research on DAOs. We use the seven-step iterative model by Nickerson et al. (2013) and extended this model with an eighth step; namely, a qualitative evaluation using semi-structured expert interviews, following the approach described by Finkbeiner (2017). Taxonomies offer a list of dimensions that each have a set of characteristics. However, only one character can be assigned to each dimension for a single object of study Nickerson et al. (2013). We chose this approach, because it is field-tested in the area of information systems, including in the field of blockchain-based technology (Fridgen et al. 2018; Hofmann et al. 2021). We depict the complete approach in Figure 1.

Haas et al. (1966) list the possible uses of taxonomies with an empirical basis: they may be (1) strategically helpful for refining hypotheses; (2) aid in the investigation of validity and utility of intuitively based typologies; (3) serve as a basis for predicting organizational decisions or change. We use argument (2) to challenge the proposed, intuitive taxonomy of Wright (2021).

While there has not been any focus on taxonomies in DAOs, the general research on taxonomies for scientific purposes, especially in organizations, is vital for fundamental steps in a field; because it provides the elementals for developing and testing hypotheses (Rich 1992). It also provides the basis for midrange theorizing about the factors that impact different types of organizations, without resorting to general style theories applicable to all types of organizations (Rich 1992).

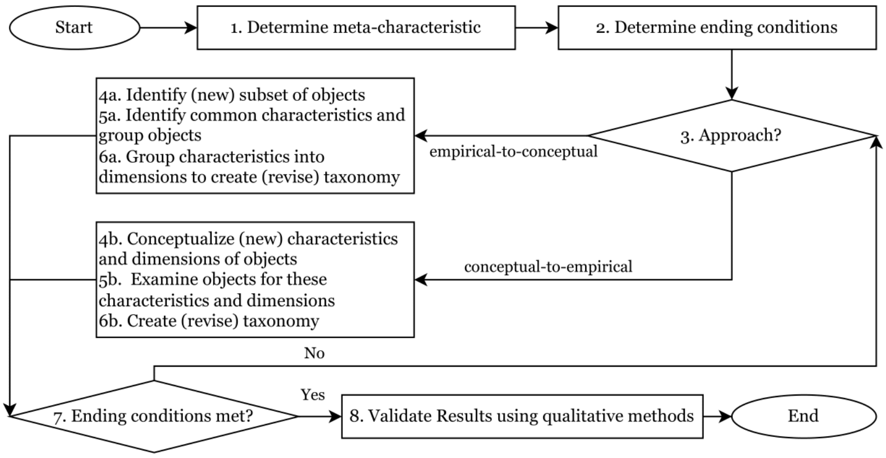

Figure 2-I. Our Extended Research Model of Nickerson et al. (2013)

As mentioned above, Figure 2-I shows our research approach, which we now explain further.

(1) The first step of the research method used is to define a meta-characteristic. “The meta-characteristic is the most comprehensive characteristic that will serve as the basis for the choice of characteristics in the taxonomy” (Nickerson et al. 2013). The meta-characteristic should be based on the purpose of the taxonomy and the purpose of the taxonomy should be based on the expected use of the taxonomy.

(2) Ending conditions are used to decide when to terminate the iterative approach. This approach only ends once all ending conditions are satisfied. To satisfy the constraints of this approach, the resulting taxonomy has to meet at least the fundamental objective ending conditions set by Nickerson et al. (2013). Additional criteria can be added, as needed.

While we use, primarily, the framework of Nickerson et al. (2013) to develop our taxonomy, we also take note of Rich (1992). He collected various pieces of advice on taxonomy development, especially dimension filtering, with the main point being to prioritize dimension quality over quantity (Mayr 1969). Furthermore, he summarizes the criteria used to define inadmissible dimensions, as listed during the application of this methodology. We use these, in addition to the subjective and objective ending criteria defined by Nickerson et al. (2013). The specific ending conditions are described in the chapter on the application of the methodology.

(4a) For the empirical-to-conceptual approach, the researcher first identifies a subset of objects that should be classified. The possible object selected can be either one that the researcher is most familiar with, any of the ones most easily accessible, or objects gathered from a review of the literature. If the number of objects selected is too great, a subset can be selected. This subset can either be random, systematic, convenient, or some other type of sample.

(5a) From this subset, the researcher identifies the most common characteristics of these objects; while the characteristics must be a logical consequence of the meta-characteristic. During this process, non-relevant characteristics may be identified and later eliminated to fit the ending conditions.

(6a) Once a set of characteristics has been identified, those characteristics can be grouped formally by the researcher, using statistical or informal techniques involving manual or graphical processes.

(7) After each iteration, the ending conditions are checked, provided all of them are satisfied. The first iteration is very unlikely to yield a satisfactory result. Therefore, a new iteration is started, where the researcher can again choose between the empirical-to-conceptual and the conceptual-to-empirical approaches. After each iteration of the design process, new dimensions may be added and existing ones eliminated.

In the conceptual-to-empirical approach, the researcher first conceptualizes characteristics and dimensions, examines objects connected with those characteristics; and then creates or updates the taxonomy. In this work, we perform two different conceptual approaches, one as described by Nickerson et al. (2013), where the researcher conceptualizes new objects on their own; and one conceptual approach, where we conceptualize new characteristics through a design space approach (Biskjaer et al. 2014). In this, we crowdsource new characteristics through collaborative brainstorming, which we then, in turn, implement into our taxonomy. In the design space, each problem defines a set of constraints that lead to possible worlds that satisfy the constraints specified. In this paper, we propose constraints for a virtual collaboration area with constraints on the receipt of new characteristics from participants. Because brainstorming in groups is inefficient (Kohn and Smith 2011), we prepare the design space and let the participants contribute individually, on an iterative basis. Therefore, we define our design space Constraint as follows:

Initial content on the digital board: Stickers with initial instructions, one example dimension with two example characteristics, and empty stickers for new answers

Initial instructions: As a member of a DAO, you might know other DAOs. Think of two DAOs that you know. What differentiates the two DAOs you have in mind from each other? Please put the dimension in which they differentiate on a sticker and mark the characteristic on it

Location: Desktop, smartphone, tablet, laptop

Tangible shapes: Circle stickers, square stickers, text fields, lines, arrows

Basic idea: Create new stickers with DAO attributes and connect them

Use situation: Individual

Interaction: Editing of stickers, coloring of stickers, deleting stickers, creating stickers, creating connections, deleting connection, ordering stickers

Purpose: crowdsource new DAO characteristics

Target audience: DAO members and web3 builders

Nickerson et al. (2013) states that upon completion of the complete taxonomy for DAOs, the result must be evaluated for its usefulness. We do this evaluation in two ways. First, we use the qualitative method of interviews, ask specific questions about usefulness; and then, we systematically analyze the interviews using Finkbeiner (2017), since we are interviewing high-ranking persons. Second, we cluster our results to identify patterns with which DAOs can be classified and then use them as a starting point for further evaluations. This, in turn, would help us to understand better what characteristics make DAOs successful.

2.3.1 Application of the Methodology

The application of our methodology is divided into the steps we have presented in Figure 2-I. We start with the definition of meta-characteristics and ending conditions.

2.3.2 Meta-characteristics and Ending Conditions

According to Nickerson et al. (2013) and the guidelines on choosing meta-characteristics, as described in the methodology, we chose *Attributes used to distinguish different types of Decentralized Autonomous Organizations* as the meta-characteristic for our taxonomy.

After each iteration, we analyzed our taxonomy regarding the ending conditions. We always started a new iteration whenever a single ending condition was not complied with. This cycle was performed until all ending conditions were met.

As described in our methodology, we use the ending conditions from Nickerson et al. (2013), as well as the inadmissible dimension constraints from Rich (1992). We start by checking the constraints from Rich (1992):

Meaningless dimensions that do not reflect the inherent qualities of the phenomena under study; (2) Logically correlated characters that prove to be the consequence of other characters; (3) Partially correlated characters where the dependence of one character on another is partial; (4) that do not vary across the sample; (5) Empirical correlations where one character can be highly related to another through empirical evidence.

We found out that none of the constraints applies to our taxonomy. Thus, we continually check the objective conditions from Nickerson et al. (2013):

All objects or a representative sample of objects have been examined. (2) No object was merged with a similar object or split into multiple objects in the last iteration. (3) At least one object is classified under every characteristic of every dimension. (4) No amendments to dimensions or characteristics were carried out in the last iteration. (5) No dimensions or characteristics were merged or split in the last iteration. (6) Every dimension is unique and not repeated. (7) Every characteristic is unique within its own dimension. (8) Each cell (a combination of characteristics) is unique and is not repeated.

After evaluating our taxonomy regarding objective conditions, we study the subjective ending conditions from Nickerson et al. (2013). These conditions require the taxonomy to be *concise*, as a lack of parsimony is a weakness; and comprehensive taxonomies could be challenging to understand for a researcher. Furthermore, it should be *robust* as a way of differentiating between the objects studied. Additionally, it must be *comprehensive;* meaning, it must be able to classify all known objects and all dimensions of objects of interest. Second, the taxonomy must be *extendible* and allow for the addition of further dimensions and new characteristics when new types of objects appear. Lastly, it must be self-*explanatory*.

2.3.3 Data Collection and iterations

We took the empirical-to-conceptual approach, starting with 4a) using a systematic sample of 35 real-world DAOs. We collected this list using (daolist 2022), a website that lists known DAOs and separates them into the categories Protocol, Service, Media, Social, Investment, Platform, and Collector. While this categorization has not been scientifically tested yet, nor is it commonly used, we decided that we would randomly sample five DAOs of each category for each iteration. We argue that the intuitive selection made by the website creators ensures a high enough degree of heterogeneity for our results to include nearly all the different dimensions for the taxonomy from this iteration alone. To gather more details about each DAO, we scraped the data from (DeepDAO 2022) by performing a snapshot of their database, using the unofficial REST-API Endpoint. This dataset primarily contains numbers about the treasury, token holders, active members, proposals, and votes.

Next, we reviewed every project website to find out as much as possible about every DAO. We performed seven iterations with each 5 DAOs, using this dataset. However, we removed 12 “DAOs” from this dataset, because they did not fit the definition of a DAO; or else because the marketing material found on their websites did not match the smart contracts and their interactions. In fact, for example, we removed the following organizations from our dataset: Yield Guild Games, UniWhales, rekt, Global Coin Research, DaoStack, PleasrDAO, HERSTORY, and Decentraland. After this, we took a non-overlapping random sample of seven DAOs, in order to perform the eighth iteration, thereby bringing our total dataset to 30 DAOs and the number of organizations examined to 42. After this, we took the Conceptual-to-Empirical approach; starting with 4b), where we added new dimensions and found them fitting for the DAOs. In total, we added five dimensions, using this approach in one iteration.

Next, we applied our design space approach. To fit our design space constraints, we used the software Miro, an online whiteboard for teams to ideate and brainstorm together. We created a new whiteboard and set up the initial content and the initial instructions. The software resolves the constraints of *tangible shape and interaction*. To fit the remaining constraints, *target audience, use situation,* and location, we invited fitting participants mostly through Discord community communication channels of DAOs, Twitter, and some peers. We used the resulting whiteboard-filled dimensions and characteristics for a conceptual-to-empirical iteration. We received over 500 views of different participants on our whiteboard and offered an incentive for every dimension presented on the board. However, only two dimensions were valid on none made it into our final taxonomy. We suspect that providing dimensions and characteristics is too complicated for the average DAO member.

Following, we perform a conceptual-to-empirical iteration using the characteristics identified by Rikken et al. (2021). Then we iterated over our list of DAOs, examined the DAOs for the given characteristics, and then updated the Taxonomy. After this, we used a stratified random sample from Messari 2022 by using the different types of DAOs available as filters such as collector, grants, impact, investment, media, product, etc. We have checked each listed organization to fit into the definition of a DAO for this work and added in total 42 more DAOs to our dataset totaling 72 DAOs, also adding Decentraland to the dataset again, as it now matches our definition.

For the creation and update of our taxonomy, we followed the guidelines of Rich (1992), respecting the specific guidelines for Breadth, Meaning, Depth, Theory, Quantitative Measurement, completeness, and recognizability.

2.3.4 Evaluation

After collecting 30 data points, we conducted seven semi-structured expert interviews for the evaluation, which lasted between 20 and 30 minutes. The interviews were performed and analyzed as described by Finkbeiner (2017). The interviews provided valuable real-world insights into DAOs and allowed us to perform conceptual-to-empirical rounds, adding two new dimensions to the taxonomy. Additionally, we have performed a second round of expert interviews with six experts and asked them about all objective ending conditions and confirmed that there were no duplicate dimensions or categories, no dimensions or categories that are a combination of one or the other, and that there are no meaningless dimensions or categories. Additionally, we have asked the experts about the preciseness, completeness of attributes, extensibility, and clarity of the taxonomy on a scale from one to ten. The average score for preciseness in our interviews was 8.5, completeness of attributes 8, extensibility 7.3, and clarity 7.1.

2.4 Taxonomy of Decentralized Autonomous Organizations

We present the final taxonomy in Table 1. It consists of three main categories, seven sub-categories, 20 dimensions, and 53 characteristics that we have defined according to the previously explained research method used to describe DAOs. We grouped the dimensions into sub-categories that we then grouped into main categories. Examples of dimensions are Community Membership Access, and Governance Voting is fully On-Chain.

		Dimension	**Characteristics**				
Community	**Membership**	Access	Open (56)	Token Ownership (12)	Token Staked (1)	Invitation (3)	
		Type	Profit from Tokens (43)	Community (17)	Decider (12)		
		Is hierarchical	Yes (8)	No (64)			
		Anonymity	Anonymous (16)	Pseudonymous (53)	Known (3)		
	Meta	Contributor Rewards	REP Token (5)	Governance Token (42)	Other Token (25)		
		Purpose	Community Building and Engagement (13)	Product Building and Management (48)	Investing or Fund Raising (11)		
Governance	**Toke**	Type	Singular (65)	Primary and Reputation (7)			
		Supply Cap	Capped (61)	Uncapped (11)			
	Process	Entry Barriers	Ownership (58)	Ownership + Application (5)	Invitation (2)	Staking (6)	Election (1)
		is fully Public	Yes (66)	No (6)			
		Execution	Automatic (20)	Manual (52)			
		has Proposal Creation Restricted	None (13)	# Tokens Owned (37)	Allowlist (22)		
	Voting	is fully On-Chain	Yes (18)	No (54)			
		Power	# Tokens Owned (60)	Per Individual (5)	# Tokens Staked (7)		
		Limits	None (66)	Per Address (6)			
Treasury	**Meta**	Diversification	None (37)	Some (7)	Very (28)		
		Stakes Tokens	Yes (34)	No (38)			
		Capital Gain	Token Sales (10)	Services (47)	Investment Returns (15)		
	Setup	Initial Airdrop	Yes (32)	No (40)			
		Initial Token Sale	Yes (43)	No (29)			

Table 2-I. A Taxonomy of DAOs

In addition to our taxonomy and its dimensions and characteristics, we also highlight those dimensions removed in our iterations, in order to compile this taxonomy; the reason being that they do not fit taxonomies. But they do offer insight on inadmissible characteristics for DAOs, which some self-proclaimed DAOs have but which are not compliant with our definition of DAO. Table 2-I highlights the inadmissible characteristics in italic. Once a DAO has this characteristic for the dimension concerned, we no longer consider it to be a DAO.

Dimension	**Characteristics**
Treasury Type	Smart Contract – *Single Owner – None*
Treasury is Public	Yes – *No*
Has Governance Voting Process	Yes – *No*
Has Governance Token	Yes – *No*

Table 2-II. Inadmissible Characteristics of DAOs

In addition to inadmissible characteristics, we have found other characteristics that can be used to assess DAOs but do not offer any benefit to our taxonomy. For Token Holders, Community Participation, and Treasury Size, we provide a segmentation into different sizes that we deem to be important for an assessment of DAOs in Table 2-III. We created the segments by looking at the raw values from our complete dataset and clustered them into groups that had the least inner distance within the clusters.

Dimension	**Characteristics**
Token Holders	Very Small – Small – Medium – Large – Very Large
Community Participation	None – Some – High – Very High – Full
Treasury Size	None – Very Small – Small – Medium – Large – Very Large – Main
Governance Process Portal	Standard-Software – Custom – None
Has Legal Entity	Yes – No
Underlying Blockchain	Ethereum – Other – Multiple

Table 2-III. Assessment Characteristics of DAOs

We now elaborate on each main category, sub-category, dimension, and characteristics. We also explain our additional assessment characteristics of DAOs.

2.4.1 Community

Communities are an essential part of every DAO. We have found several options on how membership in DAOs work and what parameters a community may have. Here, we describe these options and parameters.

Community Membership Access: Regarding access to memberships within a community, we have found out that a community can either be *Open, Token Ownership, Token Staked, or Invitation. Open* means that anyone can join the community, regardless of affiliation or ownership. The access type *Token Ownership* means that the DAO aspirant has to own a predetermined number of tokens in order to join a community. *Token Staked* means that a DAOs aspirant has to stake (lock) tokens for a set period, in order to join a community. *Invitation* refers to very limited access only granted when the DAO aspirant is part of the Multi-Signature wallet of the DAO. In most cases, the signature owners are decided at the founding of a DAO and are changed very rarely afterwards.

Community Membership Type: The type of membership refers to the purpose of the membership, which can be *Profit from Tokens, Community, or Decider/MultiSig. Profit from Tokens* describes a membership, where a member buys DAOs tokens with the sole expectation of monetary gain. *Community* represents a membership, where the main value-added for the user is access to the community and its knowledge. *Decider/MultiSig* refers to a membership type, where the primary purpose is to decide on proposals brought up in the DAO.

Community Membership is hierarchical: A Community can have single or multiple levels or tiers. For example, members can be dolphins or whales, where a dolphin has very few tokens of a DAO, while a whale owns a vast number of tokens; and both are given different ranks with different permissions within a DAO. Since there are various possibilities of levels, we only differentiate between *Yes* – has levels and *No* – does not have a hierarchy.

Community Membership Anonymity: We found out that Communities can have various anonymity levels, such as *Anonymous, Pseudonymous,* and *Known. Anonymous* means that the members are only known by their wallet address and cannot be linked to pseudonyms or real identities. *Pseudonymous* describes a Community, where members have nicknames, such as "Satoshi Nakamoto"; these are not their real names but are used consistently by users. *Known* characterizes a membership, where all members are known by their real name.

Community Meta Information – Contributor Rewards: Each DAO needs members or contractors working for it to evolve. There are different options for rewarding contributors, such as *REP Tokens, Governance Tokens,* or *Other Tokens*. Reputation Tokens (*REP Tokens, for short)* are non-transferable tokens that can be used mostly for voting in DAOs. *Governance Tokens* are the same, but they are transferable. *Other Tokens,* such as Ethereum, Bitcoin, or USDC, may also be used to reward contributors.

Community Meta Information – Purpose: The dimension *Purpose* tries to describe roughly what a DAO's main goal is. We have found that there are three groups: *Community Building and Engagement*, *Product Building and Management,* and *Investing or Fund Raising*. *Community Building and Engagement* is about creating awareness for anything exploiting the concept of a DAO. *Product Building and Management* can be a service for DAO tooling, a service for creating DAOs themselves, hosting infrastructure as a server, etc. The main goal of *Investing or Fund Raising* is to find either profitable ventures to invest in as a group or to raise funds for what may sometimes be charitable purposes.

2.4.2 Governance

The Governance of a DAO describes how a DAO manages itself, allocates funds, and decides in which general direction to move. It is the core of every DAO, and lots of different methods for handling governance in a DAO are available. Here, we provide a list of dimensions, by means of which DAO Governance can be best categorized.

Governance Token Type: *Token Type* specifies the underlying options of the governance token—our taxonomy states the options *Singular* and, *Primary and Reputation*, where *Singular* is a single token type such as ERC20, ERC721, etc. *Primary and Reputation* can be a single token of any kind with the addition of a reputation token which the DAO hands out for contribution.

Governance Token Supply Cap: *Token Supply* can either be *Capped* or *Uncapped,* where *Capped* describes an unchangeable maximum supply set in a smart contract. *Uncapped* allows for further minting of governance tokens. For no governance token, we default to *Capped* for having a fixed number of zero tokens.

Governance Process Entry Barriers: We make a general distinction between access to the community of a DAO and access to the governance of a DAO. The entry to governance is always gated through one of the following: *Token Ownership, Invitation, Token Ownership and Application, or Token Staking. Token Ownership* means that members have to own a token to vote. *Invitation* means that members have to receive an invitation from the DAO before taking part in governance. *Token Staking* refers to members needing to stake tokens before being admitted to the governance process. *Token Ownership and Application* relates to members having to apply to the DAO and holding a token to vote.

Governance Application is fully Public: Here, we refer to the accessibility of the governance process. If the entire process is visible outside without any barriers, we use the characteristic *Yes*. Otherwise, *No*.

Governance Process Execution: Once a proposal has passed, the result of the proposal has to be executed. For example, if a proposal is passed to allocate X number of tokens to Y, this transaction must be executed. It can either be executed *Automatically,* for example, using connected Smart Contracts, or *Manually,* where one or more members of the DAO must issue the transaction in good faith.

Governance Process has Proposal Creation Restricted: Proposals build the core of every governance system in a DAO. DAOs can restrict who can create a proposal. This restriction is, for example, useful in very large DAOs to prevent spam and keep focus. The possible characteristics are *None, Number of Tokens owned, Allowlist. None* allows everyone to create a proposal. The *Number of Tokens owned* requires the proposal creator to hold a specific number of tokens; while *Allowlist* means that someone or a group has to add the member that wants to create a new proposal to the Allowlist.

Governance Voting is fully On-Chain: This dimension represents the ultimate goal of a DAO: Complete decentralization on a Blockchain. Every governance step is performed on a Blockchain, and no part is handled off-chain. Our taxonomy allows the characteristics *Yes* and *No* for this dimension.

Governance Voting Power: We define how voting power is distributed in a DAO with this dimension. It can either be the *Number of Tokens Owned*, *Number of Tokens Staked, or Per Individual.* With the *Number of Tokens Owned,* the voting power is directly correlated to the weight of the vote of a DAO member. With the *Number of Tokens Staked*, the voting power results directly from the number of Tokens a DAO member. *Per Individual* describes a case where a few individuals each have the same voting power.

Governance Voting Limits: A DAO can also impose restrictions on the voting power of a single DAO member. For example, a maximal number of eligible owned or staked tokens can be set per DAO member. Therefore, we use the characteristics *None* and *Per Address, w*here *none* means no limit'; and *Per Address* the arbitrary limit imposed on each DAO member.

2.4.3 Treasury

In the Treasury, all assets of a DAO are stored. The Treasury can take all possible forms of asset management, like holding many different fungible or non-fungible tokens or even real-world assets. In a DAO, the governance process decides how to effectively use the assets to achieve to goals of the DAO.

Treasury Meta Information – Diversification: The Treasury of a DAO can have many different forms. For example, at the beginning of a DAO, a governance token has been minted and the DAO Treasury contains only its governance token. If the DAO decides to sell some of its governance tokens, the Treasury can diversify with Ethereum or USDT (USD Tether, a typical stable coin). Additionally, the DAO can decide to buy many different tokens, so that the value of the Treasury is not dependent on a single or a few tokens. Therefore, we define the characteristics *None*, *Some*, and *Very*, where *None* means more than 95% are held in the DAOs own governance token; *Some* refers to more than 5%, but less than 25% are held in tokens that are not the own governance token; the characteristic *Very* describes a Treasury where more than 25% of all tokens held are not the own governance token.

Treasury Meta Information – Stakes Token: A Treasury can stake tokens for use cases like monetary gain by taking part in a Proof-Of-Stake algorithm, provision of liquidity to a DeFi

Application, or the gain of the staked voting power. However, there is a long list of possible options for staking tokens and most DAOs use many different use cases for staked tokens. Therefore, we introduce this dimension as a flag characteristic with *Yes* and *No* options.

Treasury Meta Information – Capital Gain: With this dimension, we describe how the DAO can increase the funds in its Treasury. We observed three ways: *Token Sales, Services,* and *Investment Returns. Token Sales* can be either initial token sales or ongoing token sales. We describe the initial token sale in the Treasury setup dimensions. Ongoing token sales are, for example, team tokens that have been allocated for the team. DAOs can, for instance, define this in their Tokenomics – the key figures of the initial and ongoing token allocation. *Services* can be the sale or the access to software that the DAO owns or provides. Lastly, a DAO can receive *Investment Returns* on its investments in other DAOs that provide services, DeFi applications, NFT collections, etc.

Treasury Setup – Initial Airdrop: There are different ways to distribute the governance tokens initially. One way of performing this distribution is to airdrop tokens to a set of users. *Airdropping* means that the users receive the tokens without paying for them. A group of eligible users for an airdrop can be chosen by selecting users from adjacent organizations, users of typical web3 applications, or previous contributors of the DAO. Our taxonomy offers the flag characteristic *Yes* and *No* for this dimension.

Treasury Setup – Initial Token Sale: Contrary to the *Initial Airdrop,* where the user receives the tokens for free, the *Initial Token Sale* always requires the token receiver to pay for the tokens. Examples of this type of Token Sales are Initial Coin Offerings (ICOs), Initial Exchange Offerings (IEOs), and Initial Decentralized Offerings (IDOs). Since there are countless sales methods, our taxonomy uses a flag characteristic with the values *Yes* and *No* for this dimension.

2.4.4 Inadmissible Characteristics of DAOs

Treasury Type: The *Treasury Type* dimension specifies how DAO members can access the fund. Our taxonomy describes the possibilities of a *Single Owner,* and *Smart Contract.* A single owner has full control over the treasury, whereas a smart contract is governed by a governance system or a group of multi-signature holders.

Treasury is Public: This dimension, with flag characteristics *Yes* and *No,* states if anyone can view the balance and content of the DAO Treasury at any time.

Has Governance Voting Process: The dimensions for the voting process states if there is a governance voting process in a DAO. The available options are *Yes* or *No*.

Has Governance Token: This dimension describes if a Governance Token exists. Without any governance token, a DAO cannot perform formal decentralized governance. We describe it as a flag, offering the options *Yes* and *No*.

2.4.5 Assessment Characteristics of DAOs

Token Holders: Our Taxonomy offers five characteristics for Token Holders within a DAO. We define

$$Token\ Holders = \begin{cases} very\ small & for\ x < 100 \\ small & for\ 100 \leq x < 2500 \\ medium & for\ 2500 \leq x < 12500 \\ large & for\ 12500 \leq x < 50000 \\ very\ large & for\ x > 50000 \end{cases}$$

Where $x = |DAO\ Token\ Holders|$

Community Participation: The Taxonomy uses five characteristics for activity in a DAO. We define

$$Participation = \begin{cases} None & for\ x = 0\% \\ Some & for\ 0\% < x < 25\% \\ High & for\ 25\% \leq x < 90\% \\ Very\ High & for\ 90\% \leq x < 100\% \\ Full & for\ x = 100\% \end{cases}$$

Where $x = \frac{|DAO\ Average\ Active\ Voters|}{|DAO\ Token\ Holders|} \times 100\ in\ Percent$

None, Some to Very High, and Full each create very distinct categories. However, with Some to Very High included in the taxonomy, a more granular distinction about some types of DAOs can be performed.

Treasury Size: Our taxonomy offers five characteristics for Treasury Size in a DAO. We define

$$Treasury\ Size = \begin{cases} none & for\ x = 0 \\ small & for\ 0 < x < 5000000 \\ medium & for\ 5000000 \leq x < 50000000 \\ large & for\ 50000000 \leq x < 500000000 \\ super & for\ x > 500000000 \end{cases}$$

Where $x = Treasury\ size\ in\ US - Dollar$

We developed this distinction, performing a semantic partitioning of our dataset with clustering and looking for breakpoints, where the structure of a DAO changes drastically. Furthermore, Treasury size does not include Total Value Locked (TVL) but only the number of tokens useable by the DAO.

Governance Process Portal: This dimension allows us to measure the maturity level of a DAO. The possible characteristics are *Standard Software, Custom*, and *None*. *DAOs* use *Standard Software* to kickstart the governance quickly. Once DAOs mature, more *Custom* solutions are deployed. We have found that all DAOs that use *Standard Software* in our sample use a tool called Snapshot (Snapshot Labs 2022). *None* means that voting is not supported by special software and must be performed manually.

Has Legal Entity: Specifies whether a DAO has an underlying legal structure.

Underlying Blockchain: States the underlying blockchain hosting the smart contracts of the DAO.

2.5 Application and Validation of the Taxonomy

We perform agglomerative clustering on our dataset to apply the taxonomy to a use case. We receive combined characteristics that build categories of DAOs that are not set arbitrarily but are calculated with scientific methods. We have performed agglomerative clustering, using the Wards method, to reach this goal; this is because it has worked well for analyzing other taxonomies and is the appropriate choice for categorical data (Fischer et al. 2020; Gimpel et al. 2018; Hofmann et al. 2021). Our selection of the number of clusters was supported by calculating the Silhouette score (Berkhin 2006), the Davis-Bouldin score (Davies and Bouldin 1979), and the Dunn Index (Dunn 1974). These measures evaluate the quality of the clustering results. The silhouette score is proportional to the inter-cluster distance, while the Davis-Bouldin score represents the average similarity measure of each cluster with its most similar cluster (Pedregosa et al. 2011). According to both scores, five to eight clusters would be optimal. Five clusters yield 0.38 for the Silhouette coefficient and 2.1 for the Davis-Bouldin Score, respectively. We also implemented the Elbow Method, to help us find the correct number of clusters (Pedregosa et al. 2011). From Figure 2-II. Distortion Elbow, we can see that the optimal number of clusters, according to the Elbow score, is k=6. Semantically, five clusters make the most sense. To confirm this, we did a visual approach using the Dendrogram in Figure 2-IV by looking at the different existing clusters and how they split when a new cluster is added. We have also done this with all experts in the interviews to find the most fitting number of clusters resulting in five as the most named.

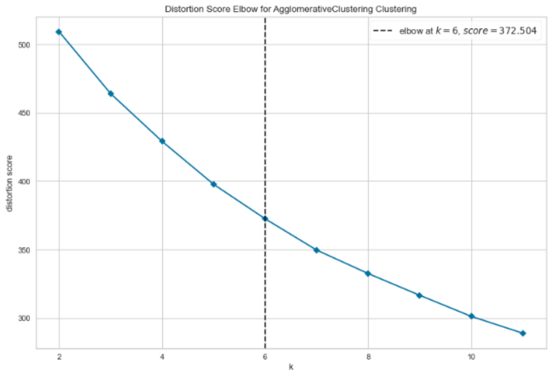

Figure 2-II. Distortion Elbow

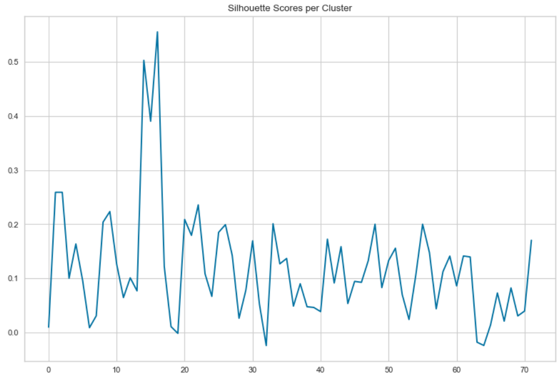

Figure 2-III. Silhouette Scores

Next, we describe the five semantically different clusters and highlight their unique characteristics.

2.5.1 Cluster Red: Off-Chain Product and Service DAOs with Community Focus

Product and Service DAOs have an open community. Their purpose is to build products and manage them. The primary purpose of participating in the community as a token holder is to profit from a price increase of the governance tokens. Contributors of the DAOs are rewarded with governance tokens. To participate in the governance process, tokens are needed, but the process is open to the public. Voting requires governance tokens. Creating a proposal is restricted to members that own tokens. Governance decisions are executed manually by a group of multi-signature holders governing the treasury. The initial token distribution is done with an initial airdrop and the DAOs gain capital through their services.

2.5.2 Cluster Green: On-Chain Product and Service DAOs

On-chain product and service DAOs also have an open community. Users actively participate in the DAO for community aspects. The business models of these DAOs are a service on the chain, which charges the user fees; and these fees are then used to increase the price of the governance token. The governance process is restricted to members that own a certain number of tokens and the weight of a single vote is determined by the number of tokens owned. The execution of the governance vote is done completely on-chain and does not require a team member to act.

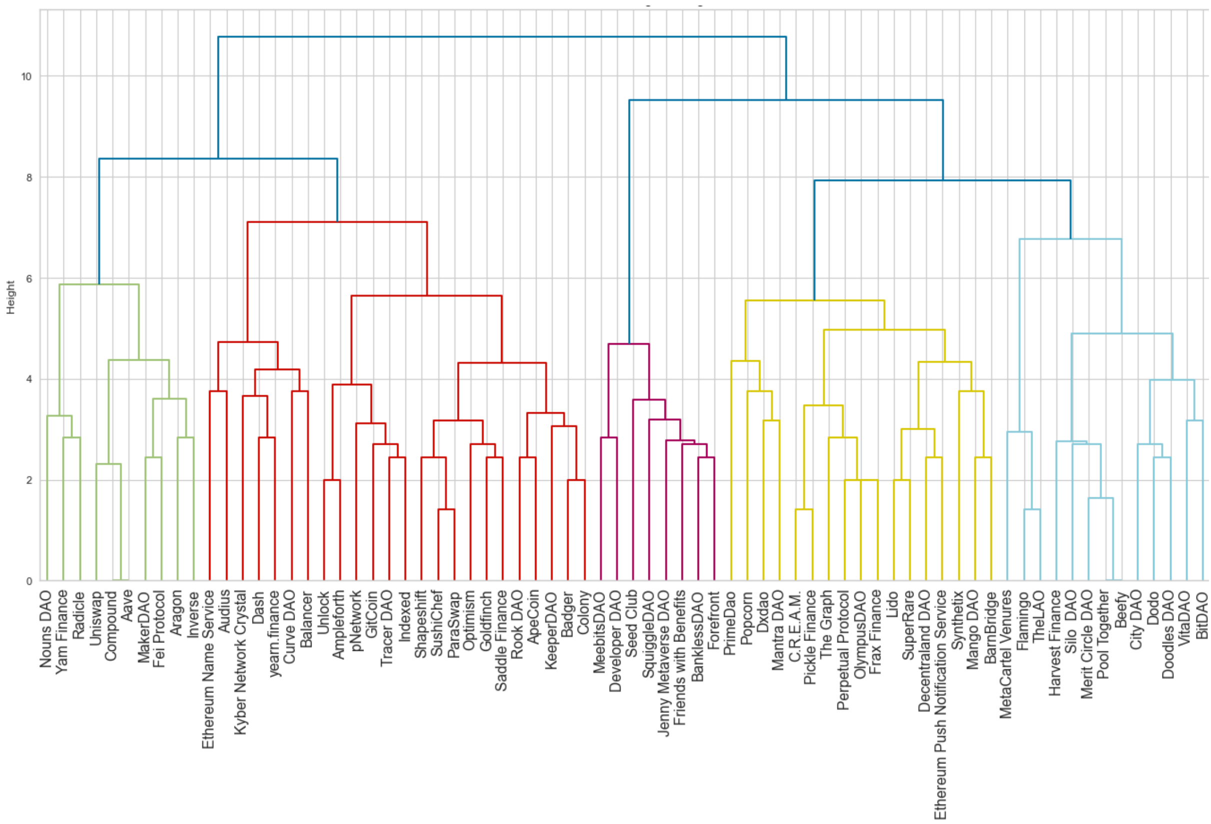

Figure 2-IV. Resulting Hierarchical Dendrogram

2.5.3 Cluster Blue: Investment-focused DAOs

The primary purpose of investment-focused DAOs is investing or fundraising. Members have to own tokens to participate in the governance process and also have to own tokens to create a proposal. All members are known by their pseudonyms and gain monetary value by holding their governance tokens. This rises in price when the investment returns of the investments actioned by them through their governance process result. An initial token sale allocates the initial token distribution. The treasury of investment-focused DAOs is very diversified. Their community is open to the public and contributors are rewarded with other tokens.

2.5.4 Cluster Purple: Networking-focused Community DAOs

The primary purpose of networking-focused community DAOs is community building and engagement. In turn, the primary purpose of community members is to connect with the community, which is gated by token ownership. Members of the community are known by a pseudonym. These communities gain capital by selling their governance token. The initial token distribution is either done with an airdrop or with a token sale. Their governance process is not visible to the public and requires the ownership of tokens to participate. Only members on an Allowlist can create new proposals.

2.5.5 Cluster Yellow: Off-Chain Product and Service DAOs with Investor focus

Product and Service DAOs have an open community. Their purpose is to build products and manage them. The primary purpose of participating in the community as a token holder is to profit from a price increase of the governance tokens. Contributors of the DAOs are rewarded with other than the governance tokens, mostly stable coins or Ethereum. To participate in the governance process, tokens are needed, but the process is open to the public. Voting requires governance tokens. Creating a proposal is restricted to members that own tokens. Governance decisions are executed manually by a group of multi-signature holders governing the Treasury. The initial token distribution is done with an initial token sale and the DAOs gain capital through their services.

		Dimensions	Cluster Red (33%)	Cluster Blue (18%)	Cluster Purple (11%)	Cluster Green (13%)	Cluster Yellow (23%)
Community	Membership	Access	Open	Open	Token Ownership	Open	Open
		Type	Profit from Tokens	Profit from Tokens	Community	Community	Profit from Tokens
		Is hierarchical	No	No	No	No	No
		Anonymity	Pseudonymous	Pseudonymous	Pseudonymous	Anonymous	Pseudonymous
	Meta	Contributor Rewards	Governance Token	Other Token	Other Token	Governance Token	Governance Token
		Purpose	Product Building and Management	Investing or Fund Raising	Community Building and Engagement	Product Building and Management	Product Building and Management
Governance	Token	Type	Singular	Singular	Singular	Singular	Singular
		Supply Cap	Capped	Capped	Capped	Capped	Capped
	Process	Entry Barriers	Ownership	Ownership	Ownership	Ownership	Ownership
		Is fully Public	Yes	Yes	No	Yes	Yes
		Execution	Manual	Manual	Manual	Automatic	Manual
		has Proposal Creation Restricted	#Tokens Owned	#Tokens Owned	Allowlist	#Tokens Owned	#Tokens Owned
	Voting	is fully On-Chain	No	No	No	Yes	No
		Power	#Tokens Owned	#Tokens Owned	#Tokens Owned	#Tokens Owned	#Tokens Owned
		Limits	None	None	None	None	None
Treasury	Meta	Diversification	None	Very	None	None	None
		Stakes Tokens	Yes	No	No	No	Yes
		Capital Gain	Services	Investment Returns	Token Sales	Services	Services
	Setup	Initial Airdrop	Yes	No	No	No	No
		Initial Token Sale	No	Yes	No	Yes	Yes

Table 2-IV. Results of the DAO Clustering

2.6 Conclusion and Outlook

Even though DAOs have been around since 2014 (Buterin 2014), they have only recently started receiving attention from the general public. Since then, very little research has been conducted on the inner workings of DAOs; while no research at all has been done regarding data-driven taxonomies. This situation has meant that very little is known about the different potential dimensions of DAOs and which characteristics DAOs may potentially adopt. Since DAOs have emerged as a new type of organization, information system researchers, developers, and investors currently experience difficulty in understanding the different forms of DAOs. To bridge this research gap, we have developed a data-driven taxonomy of DAOs.

We collected data on 102 organizations, of which 72 qualified as DAOs under the definition we used in this work, as derived from Rikken et al. (2021). Following the approach of Nickerson et al. (2013), we performed several empirical-to-conceptual iterations, in order to build our data-driven taxonomy. In addition to the empirical-to-conceptual iterations, we performed conceptual-to-empirical iterations. One of the iterations received its conceptual data from a design space that we defined, using design space constraints (Biskjaer et al. 2014). Finally, we performed a qualitative validation with two rounds of semi-structured expert interviews. The resulting taxonomy contains three main categories, seven sub-categories, 20 dimensions, and 53 characteristics. While we do not consider this taxonomy final, as the field is still moving very fast and new DAOs are founded every day, we have proven that it is solidly based. We have done this by performing agglomerative clustering on our dataset, which we then fitted into the taxonomy. The clustering resulted in five distinct clusters, each describing a different type of DAOs instead of nine or more, as commonly referred to in the relevant blogs (Cointelegraph 2022).

We contribute to both theory and praxis by providing a non-intuitive data-driven taxonomy that can be used for further research and the creating or fine-tuning of DAOs. We contribute to the descriptive knowledge of a relatively new research area by providing technical descriptions, to the best of our understanding of all the dimensions a DAO could potentially have. This fosters general expertise on DAOs and their inner workings within the research community. The clustering allows researchers to target a specific type of DAO as every cluster we have found contains a set of DAOs that each follow the same goal. With this, a researcher can define dependent variables according to a cluster of DAOs and does not have to work with DAOs as a grand unit. DAOs in general are very diverse and cannot easily be used for further research into the success, maturity, or completeness of a DAO, however, we argue, that with our taxonomy and the clusters it makes this kind of research more accessible as a group of DAOs can be targeted instead. Practitioners can leverage this framework to build applications that score the maturity, performance, completeness or other key value indicators to provide insights into DAOs for investments or general selection criteria.

While we have made a considerable effort to obtain high-quality, extremely accurate data, we have to acknowledge that the material provided on the websites or whitepapers of DAOs, as well as in their technical documentation, do not always represent actions that have actually taken place in DAOs. For example, we identified an organization that claimed to have a decentralized execution process. Still, after looking further into its smart contracts, we found out that a single user issued all of its transactions. In this case, we fixed the data point; but the fact remains that we cannot, in the case of some characteristics, generally look this deeply inside an organization and must rely, instead, on its published materials. We consider this to be a critical issue for further predictive research and wish to highlight it specifically. For our taxonomy, we would suggest that a few single invalid characteristics in the source dataset did not affect either the resulting taxonomy or the clustering. Furthermore, all of the DAOs we examined were mostly based on the Ethereum blockchain. Once established, DAOs might take different forms on other blockchains due to possible new features, which should be noted to expand our taxonomy in the future.

DAOs can potentially disrupt traditional organizations through their flat hierarchies and direct ownership by their members. They will take many different forms in the future in many use-cases, such as crowdfunding, company structure, employee ownership, compensation for work, and like-minded communities. Many more DAOs will be created in the future, taking over many organizations in the crypto-space. They will look different from the DAOs we currently see; so new, ongoing research that expands this taxonomy will be needed.

2.7 Acknowledgements

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3 Essay II: Decoding Decentralized Autonomous Organizations: A Content Analysis Approach to Understanding Scoring Platforms

Abstract

This paper evaluates the scoring platforms for decentralized autonomous organization (DAO), examining their methodologies and highlighting their strengths and limitations. Using content analysis, we scrutinize the scoring methodologies of the Prime Rating, DAO Meter, and DeFi Safety platforms, evaluating code, documentation, security, team composition, governance, and regulatory compliance. We analyze the underlying assumptions and data sources relied upon by these platforms, using a content analysis approach. Our investigation furnishes valuable information for stakeholders, aiming to evaluate or enhance DAO scoring methodologies used by scholars and practitioners in the finance and blockchain fields. By contributing to a more rigorous understanding of DAO performance assessment, this paper supports informed decision making and promotes the development of a dependable and efficient scoring system for the decentralized financial ecosystem.

Keywords: decentralized autonomous organizations; scoring; blockchain

Current status:

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3.1 Introduction

Assessment of decentralized autonomous organizations (DAOs) is relevant for a range of stakeholders. Investors want to know if buying a DAO token would be a profitable investment. People contributing to DAOs want to know if it is worth investing their time in the organization, or if the DAO is likely to fail. They also want to know what parts of the DAO can be improved by tweaking specific parameters or adding functionality to make it more mature or its treasury safer. Governors of DAOs might need guidelines regarding what constitutes a good decision if they are changing the inner workings of their organizations. A DAO user (e.g., a decentralized finance platform, stablecoin, or oracle), needs to know how trustworthy and secure the product is and what the chances are that oversights in the design of the decentralized product might lead to a loss of funds. Regulators must know how to design rules for the minimal viable structures that a regulated DAO might require in the future.

DAOs are increasingly being studied from a scientific perspective. For example, Laturnus (2023) conducted a cross-sectional regression (from 2017 to 2022), examining 2377 proposals analyzing voting, ownership, funds, and business for transactional data to evaluate the performance of DAOs. Wang et al. (2019) addressed the security and privacy challenges of DAOs by proposing a reference model to identify future trends in DAOs. Rikken et al. (2021) reviewed and analyzed 1859 DAOs to produce a systematic definition of these organizations and to developed a governance framework for the blockchain and DAOs. Liu et al. (2021) studied governance in cutting-edge DAOs, highlighting problems and their solutions.

DAOs enable participants to remain anonymous or pseudonymous while participating in transactions. Admission to a DAO does not require permission from any central body, which makes it easier for individuals to participate. They are operated on smart contracts based on code, reducing the management and maintenance costs of control systems (Baninemeh et al. 2023).

Even though DAOs have come a long way, they are still in the early stages of development (Schneider et al. 2020). They have the potential to displace centralized intermediaries in various fields that call for complicated coordination, such as asset ownership monitoring, trade finance, the provision of digital identities, and supply chain traceability (Hsieh et al. 2018). DAOs could fundamentally alter how organizations, markets, industries, and businesses function because their decentralization offers transparency and does not require centralized intermediation between the parties for decision making (Bellavitis et al. 2023).

The primary objective of this paper is to analyze and compare the methodologies of three major scoring platforms—Prime Rating, DAO Meter, and DeFi Safety—that assess DAOs. By exploring the unique scoring mechanisms and weightages employed by each platform, this study seeks to understand the implicit priorities each service places on various aspects of DAOs.

The paper is structured as follows. Section 2 provides the theoretical background and studies conducted on DAOs, along with an overview of the research questions. Section 3 describes the applied research methods we used to conduct our research and analyze the platforms. Section 4 details how we applied our methods. Section 5 discusses our findings about the DAO scoring platforms that we analyzed. Section 6 presents the conclusions. The limitations of the research and future research opportunities are discussed in Section 7.

3.2 Related Work and Research Questions

Several studies have contributed useful research on DAOs. Faqir-Rhazoui et al. (2021) compared the three major platforms that create and manage DAOs, namely, Aragon, DAOstack, and DAOhaus. They compared growth over time, activity over time, voting system, and funds by analyzing the data from 72,320 platform users and 2353 DAO communities, extracting the data from the primary public Ethereum network and xDAI, which is the layer 2 scaling solution of Ethereum. They found significant variance among the three platforms in all four quantitative metrics. Lommers et al. (2022a) presented an accounting framework for DAOs using double-entry accounting procedures and noted that there is currently no framework for reporting DAOs transactions. Baninemeh et al. (2023) researched the DAO platform selection problem using a multi-criteria decision-making model to evaluate different alternatives and criteria for selecting the most suitable platform. They conducted three case studies of DAOs (dOrg, SecureSECO, and Aratoo), to evaluate the decision model's performance.

Fritsch et al. (2022) researched the voting power of the three most important DAO governance systems developed on the Ethereum blockchain: Compound, Uniswap, and ENS. They investigated who possessed the authority regarding voting rights and the driving factors behind the governance decisions by analyzing governance token holders' data, reviewing proposals, and reaching out to delegates. They found that these DAOs mostly voted with the majority, despite having a substantial number of delegates, thus not exercising their power.

Wang et al. (2022) conducted an empirical study of the DAOs generated and managed on Snapshot, using data collected from Snapshot and examining the basic concept of DAOs and their operating systems. They found that most of the protocols were in English, which restricted participation by non-English speakers and participants in non-English-speaking areas.

Park et al. (2023) conducted a content analysis of big data related to DAOs using text mining and topic modeling based on Latent Dirichlet Allocation (LDA). They analyzed 3,885,266 aggregated tweets from Twitter that used the hashtag #DAO and Reddit with the term "DAO" used in the content. They identified the top 100 keywords and 20 specific theme-based keywords on NFTs, finance, gaming, and fundraising from Twitter and Reddit. Their analysis emphasizes evaluating the landscape of DAOs, along with their effect on different industries.

Lommers et al. (2022b) presented the valuation framework for DAOs by developing preliminary DAO-native valuation concepts. They argued that DAO token valuation can be conducted by using either of the two approaches, the fundamental valuation approach or the comparative analysis approach. The fundamental valuation approach allows the evaluation of the DAO token based on the fundamentals, whereas, in the comparative approach, DAO tokens are evaluated based on the metrics. Implementing their framework would help evaluate the DAOs' performance in generating value for token stakeholders, as well as promote accountability among the development teams associated with the DAO.

Goldberg and Schär (2023) investigated the impact and nature of voters in DAOs using data from 1414 governance proposals. They found that the disproportionate distribution of voting power could lead to several governance and transparency challenges.

Practitioners and academics have developed various scoring methodologies for DAOs, such as Zizi (2021), DeepDAO (2023), Adjovu (2021), Axelsen (2022), Prime Rating (2023), Baserank (2023), DeFi Safety (2023), DAO Meter (2023), Regner (2022), and Mattila et al. (2022). However, no study has investigated the details of existing scoring methods for DAOs. Therefore, we formulate the following research questions:

- RQ1: What methodologies are being used by DAO rating platforms?
- RQ2: What are the similarities and differences among the DAO rating platforms?

3.3 Methodology

We take a hybrid approach to our research, following the systematic literature review methods explained by Kitchenham (2004) and the qualitative content analysis described by Krippendorff

(2019). We conduct our systematic review in three stages: planning the review, conducting the review, and reporting the results. We include both scientific and gray literature. We focus on the methodology reports of the DAO scoring platforms identified in the review for our qualitative content analysis.

We follow the suggestions of Kitchenham (2004) to structure our literature review. In the first stage of the review, the aim of the research is carried out by justifying the need for a review. Next, a review protocol is developed that describes the method for performing a review and the key factors that should be considered. This involves conducting background research on the topic, developing the research questions, developing the strategy to conduct the research using appropriate keywords, and finding authentic and reliable data sources. Next, we identify the selection criteria for inclusion and exclusion of the gathered data resources and develop a quality assessment checklist to ensure that correct and relatable literature is gathered for the topic. After assessing the gathered data and literature, we identify the methodology (qualitative or quantitative) for summarizing the data (Kitchenham 2004). The second step involves conducting and documenting the review based on the criteria established in the planning stage. The data must be presented in a suitable format that allows readers to understand and interpret them. The third step is to report the review, following the technical reporting structure (Kitchenham 2004). We dismiss the third step, and instead use the collected articles and documents for the content analysis.

Following the content analysis methodology of Krippendorff (2019), we initially segment our data through a unitization process. The individual reports constitute our sampling units, while the scoring categories and subcategories within these reports are the recording units. The contextual units provide the necessary backdrop for these categories and subcategories.

Subsequently, we construct a coding scheme (report, category, subcategory, score). This provides a structured framework for translating the raw data into a format conducive to analysis. This coding process is paramount in facilitating the subsequent phase of data examination.

In the analysis stage, we scrutinize the coded data to identify patterns, similarities, and disparities in DAOs scoring methodologies across the different reports. This comprehensive and systematic approach provides a solid foundation for our empirical investigation, allowing us to derive meaningful insights from the content.

3.4 Application of the Methodology

As a first step, we identify the need for conducting this research. We determine why a systematic review is necessary for researching DAO scoring platforms. Taking an investor and DAO member's perspective, we investigate the need to formulate measures for assessing whether DAOs are secure and valuable and develop our research questions.

We then search the literature, using the primary resources available on the internet, looking for the articles and research papers on IEEE, Google Scholar, Web of Science, Social Science Research Network, and ScienceDirect using keywords like "DAO scoring platform, "ranking of DAOs platform, "framework for scoring DAO, and "DAO analytics platform". We also review the gray literature such as articles posted on Medium related to the research conducted on DAO scoring platforms.

We identify 26 scientific articles and 10 articles submitted by practitioners for evaluation. From these, we identify three platforms suitable for our research. We review the methodologies of these platforms, drawing on their white papers, as well as on material posted on the platforms or public software repositories, such as GitHub.

At this stage, we implement the next step in our systematic literature review by determining the exclusion and inclusion criteria for application to the available data. To choose among the research papers, we opt for published papers with a date of publication later than 2017 and authored by well-known, reputed researchers who have conducted other research related to DAOs. To identify the platforms considered for this research, we use the following criteria:

- Proprietary scores and rank must be available online.
- Detailed methodology explaining how the score is calculated must be available.
- The scores must be visible to the public on the dashboard or the websites.
- The data sources for calculating the score must be mentioned.
- The number of ranked DAOs on the platforms must be greater than 30.

We employ a relevance sampling technique to systematically lower the number of units required to be considered for analysis (Krippendorff 2019). The criteria are:

- Platforms are transparent in their scoring approach.
- Platforms ensured the availability of the data and its reliability.

We decide on these criteria, as they promote trust and accountability in evaluating DAOs.

We evaluate nine platforms: Karma Score, The DAO Transparency Index, DeepDAO, DappRadar, LunarCrush, Baserank, Prime Rating, DeFi Safety, and DAO Meter. Only three of the platforms provided a detailed methodology. We ended up with DAO Meter, Defi Safety, and Prime Rating as our sampling units. We collected 98 sampling units in total.

As the last step in our systematic research, we use the data in our content analysis. We transform our data according to our coding scheme for the content analysis. Table 3-I provides examples of the coding.

Report	Category	Subcategory	Score
Prime Rating	Value Proposition	Novelty of the solution	15/250
Prime Rating	Tokenomics	Is the token sufficiently distributed?	15/250
…	…	…	…
Prime Rating	Team	Does the team have relevant experience?	10/250
DAO Meter	Treasury	Treasury type	21.3/717
…	…	…	…
DAO Meter	Security	Security audit frequency	23/717
DAO Meter	Community	Community stewards	23/717
…	…	…	…
DeFi Safety	Smart Contract and Team	Are the smart contracts easy to find?	20/315
DeFi Safety	Oracle	Is front running mitigated by this protocol? (Y/N)	2.5/315
…	…	…	…

Table 3-I. Examples of the data coding

3.5 Results

Before providing details about the platforms shortlisted for this research, we briefly discuss the platforms we eliminated from our research.

Karma Score[9] is a reputation system for DAO contributors, not a DAO platform. It aggregates the activity of each DAO contributor and generates a reputation score which is presented on a dashboard. It has a detailed methodology for calculating the Karma Score, but we removed this platform from our research, since it only calculates the score for contributors.

The DAO Transparency Index[10] is currently building the DAO Index, an analytical tool based on a theoretical foundation, to assess how a DAO implements a set of core organizing principles. The DAO index consists of three parts, a self-assessment questionnaire, an open rating database, and a rating table. The work, currently at the questionnaire stage, is still in progress, so we did not research the methodology of the index further.

[9] karmahq.xyz

[10] https://github.com/D3Cngo/dao-transparency-index

DeepDAO (2023) compiles a range of qualitative and quantitative statistics relating to DAOs by aggregating, listing, and analyzing financial and governance data. The data are presented on an interactive dashboard accessible to the public. However, we decided to discontinue further research on DeepDAO because it does not show a customized score.

DappRadar[11] tracks different decentralized apps (Dapps) across 40+ blockchains in various categories, including DeFi, NFT, and Games. It tracks live user data, transaction volume, and other financial parameters, but does not calculate a unique score, so we omitted it from our research.

LunarCrush[12] is a trading platform that possesses twenty metrics, including the Galaxy Score and Alt Rank. Even though the Galaxy Score is a proprietary score, the methodology for calculation is not detailed, and there is no indication of how the other metrics are weighed in calculating both ranks. This led us to excluding LunarCrush from our research.

Baserank (2023) is a crowdsourced crypto asset research platform that gathers data by leveraging insights from independent analysts, rating agencies, and experienced investors. The Baserank Rating measures the risk level of a specific crypto asset on a scale of 0 to 100, with assets scored below 30 considered very risky, those scored above 70 considered the least risky, and those scored between 30 and 69 considered moderately risky. One of the main reasons for excluding Baserank from our research was that certain ratings of crypto assets are only accessible to premium members, who are charged a substantial fee to register. Additionally, multiple rating agencies are involved in reviewing and ranking the crypto assets to determine Baserank ratings, but the company's website does not supply a standardized methodology for aggregating rankings from specific agencies.

[11] dappradar.com
[12] lunarcrush.com

3.5.1 Overview of the Selected Platforms

Prime Rating (2023) provides a permissionless framework for measuring the features and risks of open finance protocols. The rating scale, from A+ to D, is calculated by taking the average of a fundamental report and a technical report, with the former and latter each contributing 50%. The fundamental report measures the overall quality of a given open finance protocol by reviewing its value proposition, tokenomics, team, governance, and regulatory qualities (maximum score, 250 points). The technical review is created in collaboration with DeFi Safety, which evaluates the technical parameters of the protocol (maximum score, 185 points). The technical parameters include code, documentation, testing, security, and access controls. Prime Rating allows several raters to review the same protocol, thus increasing the authenticity of its ratings. The contributors who rated the protocols are identified on the website to increase transparency and trust. Prime Rating has reported on more than 70 decentralized finance protocols.

Figure 3-I illustrates Prime Ratings' process flow. It shows the role of the raters and review council. The raters review and score the protocols. The review council ensures that the rating team is credible and supervises the documents evaluated by the raters.

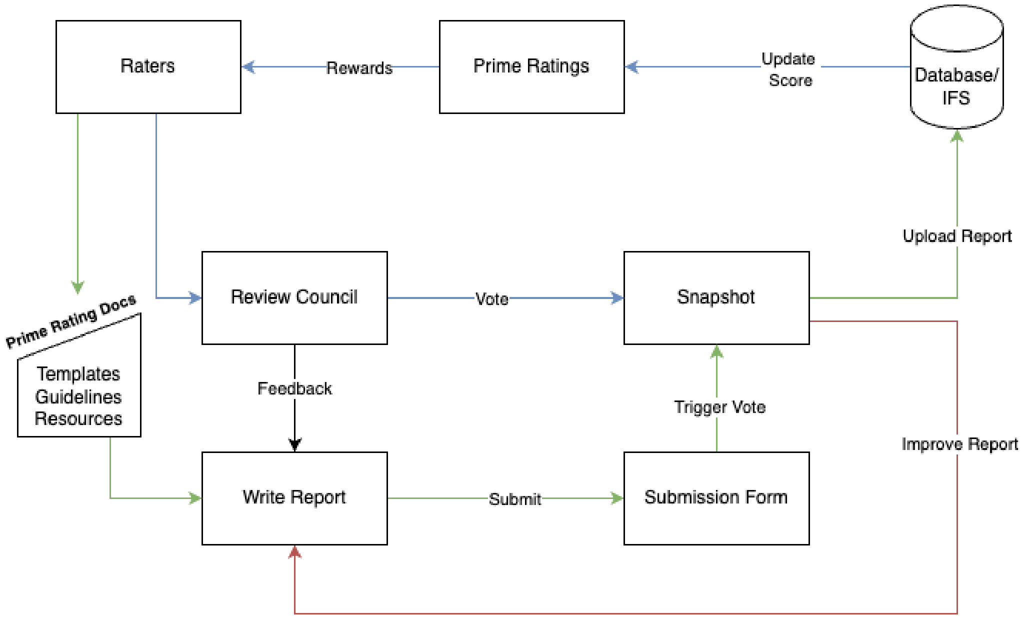

Figure 3-I. Prime Ratings' process flow for scoring a protocol (Prime Rating 2023)

DeFi Safety (2023) is an independent quality and ratings organization that evaluates decentralized finance (DeFi) protocols and scores them using a framework based on transparency. The framework is based on a process quality review (PQR) document, which details every step for calculating scores. The final score of the PQR document is a percentage, calculated by dividing the total achieved points by the total possible points. The maximum point value is 270. The framework contains six major categories: smart contract and team, code documentation, testing, security, admin control, and oracles. Each category has questions that can be answered with a yes or no, or a percentage value. The questions are weighted so that each makes a specified contribution to the overall scoring. Benchmarks listed for the percentage value questions serve as guidelines for rating the answers. The PQR document also shows how scores can be improved. At present, around 250 different DeFi protocols have been rated by DeFi Safety. Figure 3-II shows DeFi Safety's process flow.

Figure 3-II. DeFi Safety's process flow for scoring a protocol (DeFi Safety 2023)

DAO Meter (2023) is a rating platform created by StableLab. It provides a framework that incorporates both qualitative and quantitative methods for scoring the maturity of DAOs and uses numerical data and statistical tools to analyze DeFi protocols. The DAO maturity scoring framework was developed through several iterations by Nickerson et al. (2013). The maximum score is 717 points, and the points are distributed among six categories: treasury, proposal, voting, community, security, and documentation. Each category contains questions that can be answered by yes or no, or category-specific criteria that are explained in the description of the categories. A separate section on the platform explains in detail how DAOs can improve their scores. DAO Meter has reviewed and ranked 30 protocols. The contributors who rated the protocols are not identified. Figure 3-III depicts DAO Meter's process flow for creating and validating a scoring model.

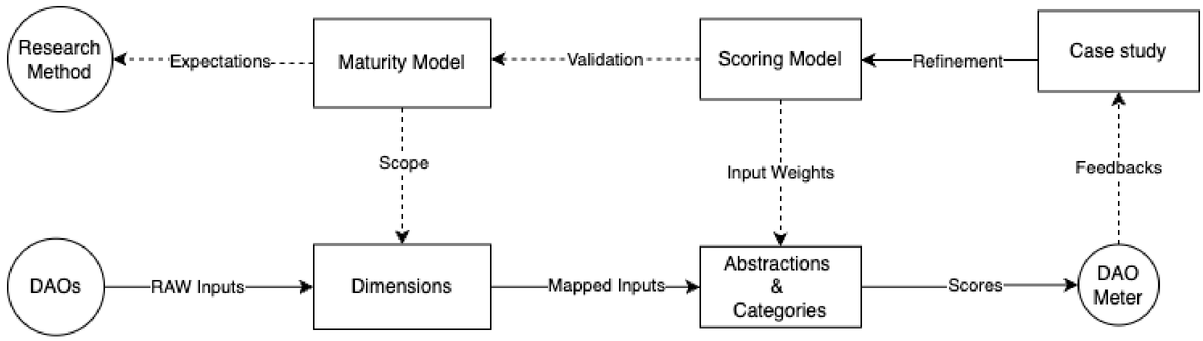

Figure 3-III. Scoring methodology of DAO Meter (DAO Meter 2023)

3.5.2 Score Overview

To determine the proportional representation of score metrics for three different platforms, with unique methodologies and different maximum scores, we convert the scoring metrics for each platform and their categories into percentages out of 100. Table 3-II shows the scaled scores for the three platforms in percentages.

Category on Platform	Prime Rating	DAO Meter	DeFi Safety
Team	9.2	32.2	14.3
Documentation	4.6	18.6	12.7
Testing	10.3		15.9
Security	4.6	12.1	28.6
Code	11.5		
Access Control	11.5		
Value Proposition	14.9		
Tokenomics	13.8		
Governance	13.8		
Regulatory Compliance	5.7		
Admin Controls			22.8
Oracles			4.8
Voting		19.8	
Treasury		11.7	
Proposal		5.6	

All numbers are percentages of the total score.

Table 3-II. Scaled platform scores

For example, the maximum score for Prime Rating is 435. One of its categories, Team, has a maximum score of 40. To convert the total score, we use this formula:

$$\text{Score out of 100} = \frac{Score\ of\ a\ specific\ category}{Total\ Score} * 100$$

$$\text{Score for the Teams category of Prime Rating} = \frac{40}{435} * 100$$

3.5.3 Comparative Analysis

3.5.3.1 Similarities—Common Subcategories in the Platforms

To assess the three platforms thoroughly, we evaluate the subcategories and questions in their scoring reports. To homogenize the scales for comparison, we convert the scoring metrics for common questions in the subcategories into percentages out of 100. Table 3-III shows the scaled scores of subcategories for all three platforms in percentages.

We use the same conversion formula mentioned in the score overview in Section 5.2, but with the common subcategory questions mentioned in the scoring report. To convert the total score out of 100 for the questions, we use this formula:

$$Score\ out\ of\ 100 = \frac{\text{Score of a specific common subcategory}}{\text{Totalscore}} * 100$$

$$\text{Score for the subcategory auditing of DeFi Safety} = \frac{70}{315} * 100$$

All three platforms, Prime Rating, DeFi Safety, and DAO Meter, consider the anonymity of the core team to be vital, but weight this feature differently. While Prime Rating and DeFi Safety apportion approximately 3.4% and 3.2% of the rating to the core team's public identity, DAO Meter allocates a more significant proportion of the rating, 5.7%, to this factor. DeFi Safety also assigns a significant portion of its total score to auditing (more than 20%), whereas DAO Meter allocates a mere 2.3%. In contrast, DAO Meter places a greater emphasis on the evaluation of public repositories (4.5% of the total score) than do Prime Rating and DeFi Safety, which allocate around 1% of their scores, with a minimal difference of 0.4%. DAO Meter and DeFi Safety allocate similar percentages of their scores (3.0% and 3.2%, respectively) to the explicit statement of ownership type; Prime Rating weights this slightly less, allocating 2.3% of its score.

Only DAO Meter and Prime Rating include the presence of active contributors or delegates in their scores, with DAO Meter according the parameter a higher weighting, 2.6%, compared to 1.1%, respectively. These two platforms also include admin key possession among their criteria, allocating it at 2.3% and 4.6% of their total scores, respectively. This highlights the emphasis placed on secure administration and control in the projects they rate.

Category on Platform	Prime Rating	DAO Meter	DeFi Safety
Team	3.4	5.7	3.2
Security	0.0	2.3	22.2
Code	1.1	4.5	1.6
Access Control	2.3	3.0	3.2
Voting	1.1	2.5	0.0
Governance	4.6	2.3	0.0

All numbers are percentages of the total score.

Table 3-III. Scaled platform scores of subcategories

3.5.3.2 Similarities—Common Platform Categories

Security, documentation, and team assessment are categories used by all three platforms, of which **security** is considered the most essential. DeFi Safety assigns it 28.6% of the total score, DAO Meter assigns it 12%, and Prime Rating assigns it 5%.

DeFi Safety and Prime Rating both emphasize the presence and significance of bug bounty programs in evaluating DAOs or DeFi projects, suggesting that they consider such programs important in the maintenance of smart contract security. They also quantify the adequacy of bug bounty programs, emphasizing the role of monetary incentives in attracting thorough code reviews from the community. DAO Meter highlights other security features of DAOs, such as security module mechanisms, security audit frequency, and whether the organization being rated has a history of catastrophic loss of funds. These shared focus areas underscore the universal importance placed on security measures and standards in evaluating and scoring decentralized financial structures and organizations. The methods for assessing and weighing these factors differs.

Documentation. All three platforms include a documentation category in their scoring systems. Documents should be easily accessible to readers. Prime Rating assigns documentation 5% of the total score, DeFi Safety assigns it 13%, and DAO Meter 19%.

The evaluation of documentation includes the availability and accessibility of white papers, financial reporting, code repositories, documentation of a given protocol's software architecture, and other supporting documents. Prime Rating and DeFi Safety also evaluate the documentation of the cover protocol architecture, and DAO Meter requires that governance and tokenomics be documented and that the financial reporting and the source code of the product and its governance be public. DeFi Safety goes a step further and requires the code of deployed contracts to be public and fully detailed in the documentation.

Team. All of the platforms include this category, but DAO Meter calls it "community". This category accounts for 32.2%, 14%, and 9% of the overall scores of DAO Meter, DeFi Safety, and Prime Rating, respectively. One of the questions asked by all of the platforms is whether the organizations being rated have non-anonymous development teams. Team anonymity can harm trust between the users and the management team because anonymous developers can disappear quickly, whereas those whose names are made public can be held accountable (DeFi Safety 2023).

Testing. Both Prime Rating and DeFi Safety have a testing category. It accounts for approximately 10% of Prime Rating's and 16% of DeFi Safety's total scores. In this category, both platforms include questions related to the testing process for code. The presence of a testing suite which is easily accessible to the general public and the availability of smart contracts are considered the most important features. The availability of instructions and guidelines for testing ensures transparency and visibility and helps in the understanding of the protocol. Also evaluated in the testing category is whether test result reports are available because they enhance the accountability of a protocol.

3.5.3.3 Differences

DAOs such as MakerDAO, Shapeshift, Aave, and Uniswap are ranked on the different DAO scoring platforms. The scores used by the various platforms to rank the DAOs and the features they consider most important vary. Prime Rating considers the value proposition of the protocol—the value it adds by solving a specific problem in the industry—to be one of the most important categories. The value proposition category includes questions related to the distinctive features of the protocols, including how they compare with the features of other protocols and how the protocol serves the needs of a specific market. The second important feature that Prime Rating considers is the token's capabilities. This evaluation includes questions related to the equal distribution of the token among markets, the purpose of the token, and whether it can serve the token holders' purposes in terms of revenue, utility, or governance.

DAO Meter evaluates preliminary discussions of protocols to identify the content or background information that led to their development. This helps to identify what problem the protocol addresses in the market. DAO Meter also evaluates security modules in the infrastructure of protocols that can protect against breaches. This category is important as it involves trust and integrity in governance.

Only DeFi Safety evaluates the possible attacks on flash loans by reviewing any available information related to this issue. Although flash loans are an essential part of DeFi protocols, the safety of investors and users must be ensured when they are used. DeFi Safety gives points to protocols that include mitigation steps in the protocol documentation.

3.5.3.4 General Observations

Each platform's ranking report contains unique focus areas and applies a specific weighting system, reflecting the relative importance the platform assigns to each category. In the Prime Rating report, value proposition is given a maximum of 65 points, reflecting its importance in the evaluation. Tokenomics and governance are each assigned 60 points, also indicating their significant roles. Team and regulatory considerations account for 40 and 25 points, respectively, which emphasizes their roles, but to a lesser degree.

DAO Meter's most heavily weighted category is community (231 points), which emphasizes community engagement and involvement in DAOs. Voting power and documentation also carry significant weight (assigned 142 and 133.5 points, respectively). Security and treasury are given 86.5 and 84 points, respectively, and proposals are assigned a modest 40 points, reflecting the relative importance of these areas.

DeFi Safety assigns the highest weight to security, allotting it 90 points out of 315, which highlights the primacy of security considerations in its assessment. Admin controls and testing carry 75 and 50 points, respectively, underscoring their significant roles. Smart contract and team and code documentation are assigned 45 and 40 points, respectively, and oracles are given the lowest weight, with 15 points.

Each report implicitly communicates its evaluative priorities by assigning weights to its exclusive focus areas. The scoring system and its weightage thus enhance the granularity and specificity of the evaluation in each report.

Figure 4 demonstrates the impact of varying scoring goals and methodologies on the evaluation of DAOs, presenting the scores of individual DAOs across the different platforms—Prime Rating, DAO Meter, and DeFi Safety. The figure thus exposes the potential range of scores a single DAO may receive under the differing evaluation criteria of each platform, while also providing a nuanced reflection of each platform's unique areas of emphasis. Through the comparative illustration provided by Figure 4, we can discern how a DAO's ranking can be distinctly affected by the unique evaluative approach of each scoring platform.

3.6 Conclusions

Our content analysis explored the scoring platforms that assess DAOs for stakeholders, investors, contributors, governors, and users. We reviewed the scoring methodologies, frameworks, and weightings of three platforms: Prime Rating, DAO Meter, and DeFi Safety. We performed a content analysis on the collected data using a scoring framework, which helped us to transform our data according to our coding scheme by grouping the data into categories. We identified similarities and differences among the three platforms by comparing the three scoring frameworks and their weightages. Although the platforms use different methodological approaches and calculations, we found that all three asked some of the same questions. These questions related to team anonymity, auditing of the protocol, the availability of open-source code, the type of treasury ownership, the presence of governance contributors, and possession of the admin keys. Although some DAOs are ranked on all three platforms (e.g., Uniswap, Aave, Compound, and Balancer), the categories that the three platforms used to evaluate DAOs are distinct. Prime Rating focuses on the solution's novelty, its market fit, and the token's capabilities. DAO Meter evaluates the maturity of DAOs, whereas DeFi Safety emphasizes security and bug mitigation.

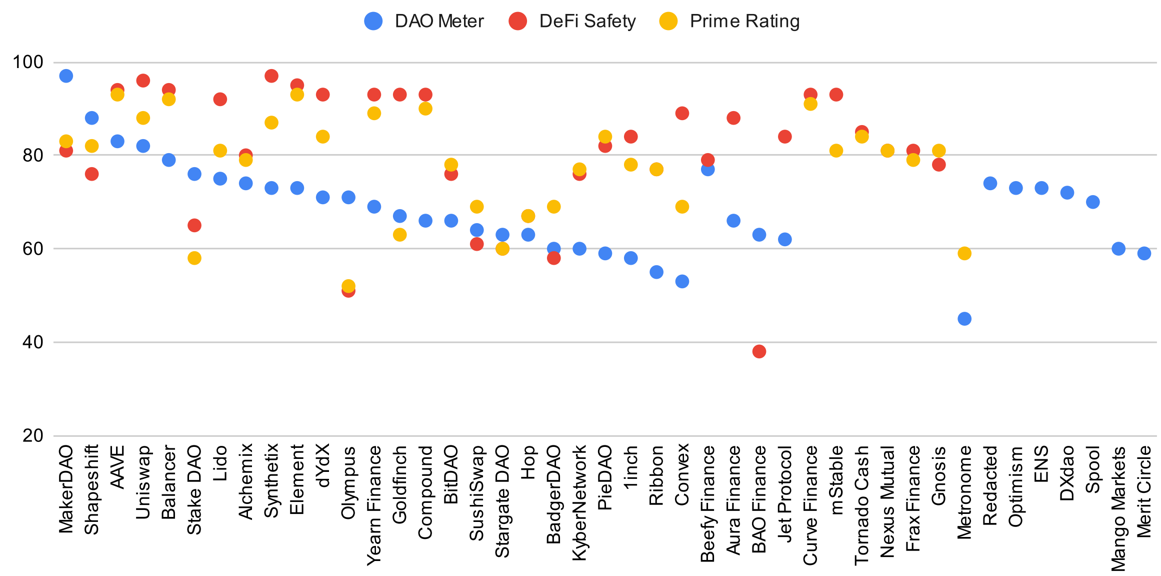

Figure 3-IV. DAOs scores on different platforms (DAO Meter 2023; DeFi Safety 2023; Prime Rating 2023)

3.7 Future Work

Researchers should examine the connection between the way in which rating platforms score DAOs and the actual performance and security of those DAOs. Currently, the scores are based chiefly on observations and qualitative factors. More reliable methods are needed as new rating platforms emerge, and they must be thoroughly reviewed and understood. Researchers should develop a scoring framework that is based on hard evidence. The scores given to DAOs by existing scoring platforms can be used as starting points, and the performance or security of DAOs can be measured over time.

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4 Essay III: From Dissonance to Dialogue: A Token-Based Approach to Bridge the Gap Between Manufacturers and Customers

Abstract

This paper presents a novel token-based recall communication system, which integrates Enterprise Resource Planning (ERP) systems and blockchain technology to enhance recall communication and cooperation between manufacturers and customers. We employed a design science research methodology to develop a set of design principles and features that support the interoperable system. Our findings demonstrate that we can significantly improve recall coordination, traceability, and co-value creation between involved parties. By focusing on the integration potential of traditional technologies like ERP systems with blockchain and token techniques, we reveal innovative synergies for both social and technical subsystems. The study explores the implications of the proposed system for both theory and practice, offering insights into the advantages and challenges of such integration. The evaluation conducted with industry experts demonstrates high reusability of the design principles.

Keywords: Blockchain, Recall Communication, Enterprise Resource Planning System, Information System Design

Current status:

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4.1 Introduction

Product quality control and efficient communication are critical elements manufacturers use to protect consumers' health and establish an image of accountability and social responsibility (Cheng & Simmons, 1994; Souiden & Pons, 2009). Maintaining internal responsibility is critical day-to-day work within manufacturing facilities, and extending it outside organizational borders must be accomplished even after the product has been delivered to the customer (Schuitemaker & Xu, 2020; G. J. Siomkos & Kurzbard, 1994). In the past few decades, manufacturing companies have implemented traceability procedures supported by enterprise resource planning (ERP) systems that ensure effective internal product traceability through upstream and downstream tracing analysis (Yuan et al., 2011).

However, when information-sharing traceability requests exceed enterprise system boundaries, numerous communication channels can be used to coordinate multiple organizations. Especially in extraordinary situations (e.g., product recall), information sharing is necessary, regardless of companies' relationships or competing interests (Wankmüller & Reiner, 2020). Data exchange is often carried out sequentially amongst direct entities such as organizations and diverse enterprise systems, posing difficulties in synchronizing the states of products, locations, and customers' health in global supply networks (Sunyaev et al., 2021).

Furthermore, when external events impact a manufacturing traceability system, various organizations and information from different enterprise systems are involved, which must be gathered to obtain a consistent picture of the recall situation (Cheng & Simmons, 1994; Wynn et al., 2011). In general, recalls are not limited to food or pharmaceutical products but have affected several industries. For example, per the 2021 Rapid Alert System for Non-Food Products (RAPEX) report, the system received 2,142 notifications about measures adopted against hazardous non-food products. Additionally, 4,965 subsequent tasks were undertaken by the network's members in response to notifications concerning dangerous products (Commission et al., 2022). From 2012 to 2021, the Food and Drug Administration (FDA) counted 1,317 recalls in Class I (most severe risk), a significant 10,168 in Class II (moderate risk), and 1,302 in Class III (least severe risk), totaling 12,787 recalls over the nearly decade-long span (Lightfoot Law, 2022).

Faced with mandatory accountability of ensuring safety of the product, recalls play an important role, as they require cooperation among several supply network actors and information-systems integration (Diallo et al., 2016). Currently, however, it is still challenging to create syntactic and semantic standards across company borders to establish a shared understanding and design an accepted traceability standard in supply networks (Islam & Cullen, 2021; Olsen & Borit, 2018; Pytel et al., 2022). These challenging conditions apply to emerging technologies and concepts like representing of physical assets as tokens to extend product traceability across organizational boundaries (Kuhn et al., 2021; Pytel et al., 2020; Sunyaev et al., 2021; Westerkamp et al., 2020). While a token-based approach in blockchains (BC) is a promising use case, less attention has been paid to recall procedures from a manufacturer's perspective and co-value creation processes with customers (Ahmed et al., 2022).

Manufacturing professionals are still confronted with managing traceability processes and providing high-quality data to ensure end-to-end traceability within their organizations' borders. To guarantee product quality and protect customers' health across several manufacturing facilities, in the future, they will also need to start with simple and practical examples to develop an inter-organizational perspective to capture the complexity of multiple organizations and enterprise systems that support their trading partners' manufacturing environments (Fleig et al., 2018; Pytel et al., 2020).

So far, enterprise systems and supply network blockchain studies are still in their infancy, making it necessary to continue research on the potential of co-value creation in customer-centric information systems (IS) and the resulting impact on manufacturers and customers (Ahmed et al., 2022; Haddara et al., 2021). Our motivation is, therefore to explore the following research questions:

- **RQ1**: How can customers and manufacturers enhance their communication across different IS to establish a co-value creation approach?
- **RQ2**: How can an IS be utilized to improve recall communication between customers and manufacturers in a recall process?

We first introduce the research method, which offers a theoretical and practical approach to answer our research questions. Subsequently, we describe relevant steps and develop an IS Artifact. Next, we provide the current state of the research and practice on various technologies and recall communication techniques. We assess these using three design cycles and an ex-post approach with industry experts with multiple viewpoints on recall procedures, enterprise systems, and blockchains to develop design principles. We offer a variety of contributions for research and practice, including a structured socio-technical modeling technique that reduces coordination efforts and novel technological advancements to transform isolated IS. We conclude our work with a discussion of limitations and future research directions that can support the adoption of co-value creation processes between manufacturers and customers.

4.2 Method

Artifact design and exploration are known in the IS community through Design Science Research (DSR) methods that propose guiding principles, phases, or processes (Kuechler & Vaishnavi, 2008; Peffers et al., 2007). In this study, we use a method that accumulates design knowledge (see Figure 4-I) and we make it available while considering that our results should be reusable for practitioners (Iivari et al., 2021; Möller et al., 2020).

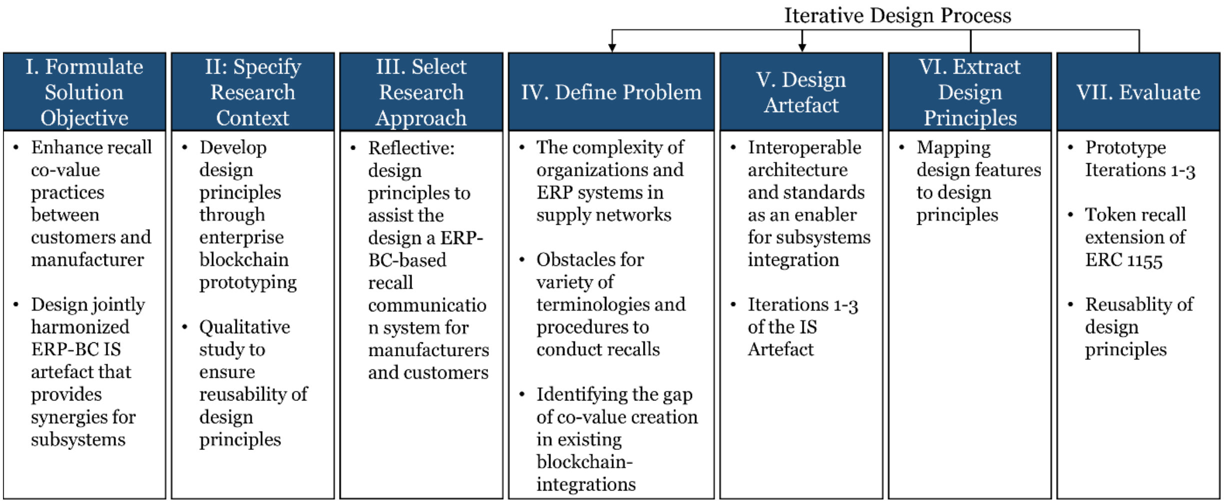

Figure 4-I. Research Methods per (Möller et al., 2020)

The goal of I—Objective is to explore the synergies between customers and manufacturers for recall communication, where social and technical subsystems must be jointly optimized in advance to operate in harmony. Therefore, we, do not exclusively focus on a prototype design but go beyond the socio-technical perspective describing social and technical subsystems as well as information about an IS artifact (Chatterjee et al., 2021).

II—Research Context thus covers developing a complex supply network scenario and enterprise BC prototype. We conduct a qualitative study to ensure that the results are as reusable as practicable for practitioners and decision-makers in the future (Iivari et al., 2021).

To develop design principles, (Möller et al., 2020) suggest two different research approaches, as discussed in III—research approaches. The supportive approach develops design principles before a prototype is developed. On the other hand, the reflective approach follows an iterative process in which the problem, an artifact, and, by abstraction, design principles are developed (Chatterjee et al., 2021; Weking et al., 2020) .The design science procedure offers the possibility to re-enter different stages to adjust the conceptual design and develop the results in several cycles (Möller et al., 2020; Peffers et al., 2007).

In IV—Problem Definition, we use a supply network scenario and a state-of-the-art enterprise system implemented in supply networks that support manufacturing environments. We further show challenges regarding the organization of recall processes and the cooperation between customers and manufacturers.

In V—Design Artifact, we start with customer-focused integration possibilities and the current technological opportunities to use a token-based approach for recall communication. We show in three iterations how we designed an artifact to bridge the gap between customers and manufacturers. The IS Artifact and results enable us to VI—extract design principles and evaluate them with practitioners in VII—Evaluate.

4.3 Problem Definition

The design, implementation, and use of traditional IS are the backbone of a contemporary information society (Su & Yang, 2010; vom Brocke et al., 2018). Improving existing IS or optimizing them for a specific purpose is an ongoing motivation for researchers and practitioners that drives to organizational culture and structure changes, known in the literature as "digital transformation" (Gregory Vial, 2021). The use and combination with novel concepts like blockchain-based tokens open many possible innovative use cases in supply networks, which can lead to conflicts between humans due to different perspectives of business, technology, legislation, or a wide range of existing complexity drivers that exist in the real world (Lesche et al., 2022; Pytel et al., 2020; Sunyaev et al., 2021). To describe the problem state holistically in the interest of research and practice, we use the Technology-Organization-Environment (TOE) Framework addressing the different dimensions of technology innovation decision-making (Chittipaka et al., 2023; Tornatzky et al., 1990).

4.3.1 The complexity of organizations and ERP systems in supply networks

Nowadays, many organizations use a wide range of IS to manage internal operations in supply networks. One of the most popular enterprise systems is ERP, which enables supply network actors to organize and optimize internal business processes using a complex relational database (Banerjee, 2018; Pytel et al., 2020). In practice, manufacturers can operate not just one ERP system but a more complex ERP landscape that is characterized by related systems, add-ons, and individual applications (Fleig et al., 2018). In general, ERPs generate a broad spectrum of **source, production, and sales** event data, providing information about products and identifiers like batches and serial numbers to enable recall-traceability procedures within company borders (Yuan et al., 2011). Alternatively, this data can also be described through a process perspective using the nomenclature of the Supply Chain Reference Model SCOR, such as source, make, and deliver events (Konovalenko & Ludwig, 2019; Wilson, 2014). These events are typically stored in enterprise systems' inventory movement tables, which use provider-specific (e.g., Microsoft, SAP, Weclapp) syntax that expresses semantically identical business processes (e.g., Source Event: Microsoft Navision: 0 – Purchase; SAP: 101 – Goods Receipt; Weclapp: IN PURCHASE ORDER) (DynamicDocs, 2023; SAP, 2023b; weclapp GmbH, 2023).

To describe and capture the complexity of a holistic supply network, we highlight all terminology in this section in **bold** and connect them to Figure 4-II. Our customer-focused recall communication scenario is based on the main SCOR events and represents a real-world production facility. For our purposes, however, the scenario is based on simulated data and an education enterprise system, which has sufficient complexity to present a more realistic use case for manufacturers that deliver products to more than one, two, or three customers (Kravenkit & So-In, 2022; Pytel et al., 2020; Westerkamp et al., 2020). Therefore, we illustrate an entire product flow organized within a single ERP system, transform enterprise data, and employ a dynamic Sankey diagram, which has been used in manufacturing environments since the 19th century (Riehmann et al., 2005).

The visualization of enterprise information includes a separable end-to-end product and process flow of two vendors (v01 and vo2), nine production plants (AA-GG), each with two storage locations and one workstation. The product flow presents 19,287 raw material movements (**input**) transformed into 6,139 finished material movements (**output**), delivering products to **194 customers**. All event data generated in a single ERP system are identifiable by a system ID. In the interest of standardization, we reuse the nomenclature for a unique enterprise system and define them as **USID** (e.g. USID 1-3) (Pytel et al., 2022). As mentioned previously, an organization can operate one or multiple ERP systems.

As a result, we boundary and define an **intra**-organizational perspective as a single organization that operates one or multiple ERP systems. Therefore, an **inter**-organizational perspective describes an integration of multiple ERPs and multiple organizations (e.g., from Org1+USID1 to Org2+USID2). The most crucial point is that information on traditional enterprise systems is bounded (Banerjee, 2018). They are not interconnected to one another to establish a traceability path, integrate the entire supply network, and provide synchronized recall states for products and customers between multiple organizations.

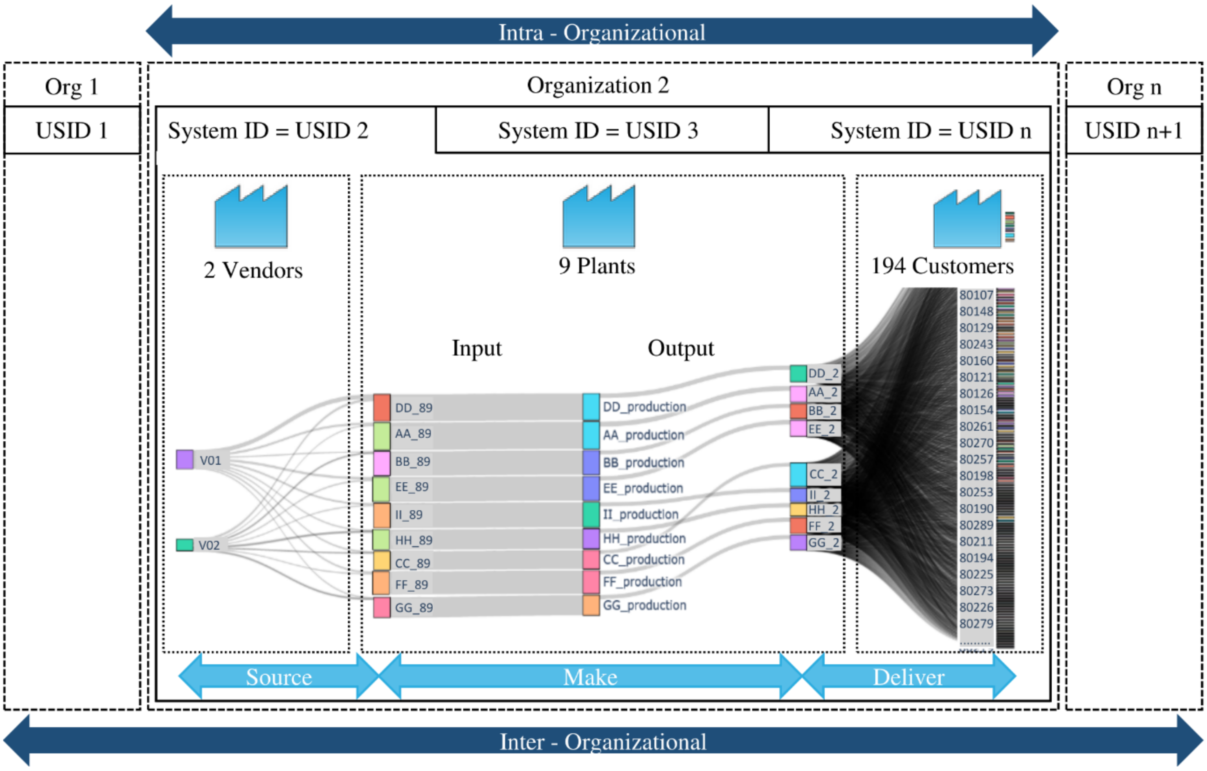

Figure 4-II. Organizations and enterprise system boundaries in supply networks

This section highlights organizational and technical challenges in designing a customer-focused recall communication system across multiple organizations and heterogenous enterprise-provider data models. Furthermore, the variety and amount of production data that could be transferred from an ERP system into a blockchain can lead to an increased effort for mapping organizational and technical structures and managing transparency concerns of sensitive objects between organizations (Pytel et al., 2022; Sedlmeir et al., 2022). (**DR1**: The enterprise systems should be mapped straightforwardly, and only essential recall communication data must be stored in the blockchain; **DR2**: The system should provide an entire recall traceability path to ensure synchronized communications between multiple organizations.)

4.3.2 Obstacles to a variety of terminologies and procedures to conduct recalls

Creating traceability in a manufacturing system is fundamental to satisfying short-, medium- and long-term targets. The system can interact with the internal and external environment depending on its emphasis (Cheng & Simmons, 1994). The internal environment mainly describes the short-term horizon and activities from a manufacturer's point of view, whereas the external environment describes medium- and long-term interactions with the customer. More than thirty years ago, four basic categories of communication were defined to describe extraordinary interactions between manufacturers and customers: “deny,” “involuntary,” “voluntary,” and “super effort” (G. Siomkos, 1989). These are still part of blockchain-supported supply network research and are alternatively described as “passive” (involuntary) and “proactive” (voluntary) communication types (Wu & Lin, 2019). However, researchers distinguish between “reactive” and “proactive” when referring to the temporal context of decision-making (Mukherjee & Sinha, 2018). Proactive, in this sense, describes a prediction toward the future rather than a willingness to communicate transparently in recall situations. We identified technology-independent terminologies such as “backward” and “forward” in food and manufacturing, which trace objects and events from different starting points. For example, “forward” describes the starting point of a raw material and its manufacturer, whereas “backward” describes the starting point of a finished material from the customer's perspective (Islam & Cullen, 2021; Jansen-Vullers et al., 2003). Different contributions also adopt this terminology considering a combination of blockchains and recall management in supply networks using the terminology “reverse” (backward) and “forward” (Agrawal et al., 2021; Jayaraman et al., 2018; Patro et al., 2021). Thus, it is difficult to come to a consistent and standardized understanding of supply network communication processes due to terminology and concept variances.

However, all these terms describe different circumstances. They are hardly seen in recall approaches and steps that we analyzed in Table 4-I for state-of-the-art enterprise systems, the global standardization organization GS1, and an example identified in a research paper:

	Step1	**Step2**	**Step 3**	**Step 4**	**Step 5**	**Step 6**
Gs1 (Gs1, 2014)	Issue Product Recall Notification	Receive Product Recall Notification	Issue Product Removal Confirmation and remove a product	Issue Product Recall Closeout Notification	Receive Product Recall Closeout Notification	Execute Closeout Record internally
Enterprise Provider (Wilson, 2014)	Problem with a product starting from raw material or customer	Find all the applicable batches	Isolate the bad batch at the lowest level	List all batches together with the locations	Send out a notice of recall, withdrawal, or hold	-
Research (Diallo et al., 2016)	Confirmation of defect	Root causes analysis	Risk analysis	Identification and localization of items	Recall	-

Table 4-I. Examples of recall steps

The comparison of research and procedures supported by enterprise system reveals an emphasis on internal tasks, such as identifying a defective product, conducting a risk analysis, and providing fewer details to external stakeholders to coordinate a recall. The GS1 recall guidelines, in contrast, focus more on external communication between involved entities to provide a potential basis for interaction between manufacturers and customers. This interaction has been conceptualized in the current research for blockchain-supported food-supply networks (Kravenkit & So-In, 2022). It should be noted that all emphasis relies on product identification and recall notification. None of the approaches considers the state of the customer's health. (**DR3**: The system should allow intuitive communication of product- and customer-health states.)

4.3.3 Related Work

Research papers that address enterprise blockchain are scarce, so the co-value creation between manufacturers and customers has barely been explored (Haddara et al., 2021). Research remains focused on why, where, and how the application of technology could add value to supply networks (Ahmed et al., 2022). According to the authors, one of the significant drivers for organizations implementing blockchains in supply networks is the demand for traceability and transparency. Enhancing the customer experience is an additional reason to employ technology (e.g., to provide product provenance). However, there is currently little discussion over how product recalls can be handled. Product recalls are a specific but important topic for which authorities such as the FDA or Rapex support organizations with recalls and risk assessment guidelines (Commission et al., 2022; Official Journal of the European Union, 2004), To assist product recalls, we list blockchain-related research articles and literature we have found in research and practice. We start by examining the technical subsystem and analyzing technical components. We extend the overview for the social subsystems to show customer integration within the manufacturer's supply network. Finally, we delineate the research of this study by introducing the Recall Communication Bridger (ReCoBridger) IS, which we describe in the next section.

	Technical Subsystem			**Social Subsystem**		
Source	**Blockchain Type**	**Technologies used**	**Enterprise System Integration**	**Domain**	**Customer Type and Co-Value Creation**	**Recall Concepts and Standards**
Jayaraman et al., 2018	Not discussed	BC, IOT	No	Health-care	No	Backward and Forward (B/F)
Patro et al., 2021	Ethereum Permissionless	SC	No	Auto-motive	No	B/F
Wu & Lin, 2019	Generic Permissioned	BC, QR, IOT	OOT, OOS, SCM, LMS, ERP	Pharma	Generic Customer	No
Agrawal et al., 2021	Generic Permissioned	SC	No	Pharma	No	B/F
Kim et al., 2018	Ethereum Permissionless	IoT, SC, ERC 721	No	Food	Private Customer	GS1 (GLN)
Kravenkit & So-In, 2022	Ethereum Permissionless	SC	No	Retail	Private Customer	EPCIS, GS1 Recall Standard, B/F
Leske et al., 2020; SAP, 2023a	Generic Permissioned	SC	ERP	Generic	Industrial Customer	SCOR Events and Status 'on hold' or 'recalled'
ReCoBridger	**EVM Permissionless**	**SC and ERC 1155**	**ERP**	**Generic**	**Private Customer**	**B/F and visual control**

Table 4-II. Existing blockchain-based approaches supporting recalls

Table 4-II presents a fragmented overview of recall scenarios that rarely explore the potential of combining traditional enterprise systems such as ERP and permissionless blockchains. The co-value creation of private customers is still in its infancy and has only been studied in two research articles. It should be noted that only two papers consider the reuse of industry standards (e.g., GS1). Different standards for consumer product recalls (e.g., ISO 10393) or any publication do not mention the ISO 307 standard that supports the development of blockchain use cases. The ISO 307 standard, on the other hand, does not yet list the communication or

management of product recalls as a use case for supply networks (ISO, 2022). It is still unclear how the link between organizational and technological subsystems may be adequately and compliantly designed considering additional environmental factors (e.g., recall guidelines). (**DR4**: The system should allow interoperability between enterprise systems and permissionless blockchains; **DR5**: The system should allow co-value creation procedures between manufacturers and private customers.)

4.4 Design of the IS Artifact

With the goal of constructing an efficient recall system, we decided on traditional and novel technologies where both manufacturers and customers are characterized by different social and technical subsystems. In the problem description, we already described a manufacturer's subsystem with traditional enterprise systems, on which private customers have no access. For establishing the link we decided on blockchain technology, particularly, an architecture built upon public blockchains. This selection was motivated by a triad of pivotal advantages which fortify the essential foundations of our system: interoperability, transparency, and decentralization.

Interoperability: Public blockchains are not owned or hosted by single corporations (e.g., software provider), also not hosted by consortiums, and are accessible without special knowledge or privileges.

Transparency: Everything on the public blockchain is known to both the customer and the manufacturer. The manufacturer can add a mapping inside their own enterprise system to augment the blockchain data with their own confidential data while the customer still has basic access.

Decentralization: Anyone can modify, extend, or use the system without needing to ask for permission, access, or source code. In theory, a third party could even set up a Decentralized Autonomous Organization (DAO) to automatically govern recall processes on the Blockchain.

We enable easy subsystem integration by connecting manufacturers and customers to the Ethereum Virtual Machine (EVM)-based architecture. Using the EVM architecture in the artifact aims to establish this connection without significantly modifying the existing manufacturer’s system and by using an application that the customer ideally already has installed on their device (e.g., smart phone). The EVM standard has already been adopted by millions of users, including 50 million active monthly users with Brave (Brave, 2022) and 21 million active monthly users with Metamask (ConsenSys, 2021).

Multiple methods or services can facilitate interaction with customers within the EVM ecosystem. One such popular service is Ethermail (ETHERMAIL, 2023), which allows users to send an email-like message to anyone with a known public address. Other protocols capable of wallet-to-wallet messaging include XMTP (Galligan, 2023) and Push (Push, 2023). Messaging applications like Blockscan Chat (Blockscan, 2023) and WalletChat (WalletChat, 2023) enable users to log in with Ethereum (**DF1**: Customer wallet notification for recall states).

4.4.1 Iterations of the IS Artifact

The development of our IS Artifact followed an iterative approach, allowing us to refine and improve the design and functionality over each iteration. This process involved three iterations, each focusing on a specific aspect of the system while addressing the challenges and limitations identified in previous iterations.

4.4.1.1 Iteration 1: Integration of blockchain-based tokens into ERP systems

Most approaches to offering customer data are based on transferring them from ERP into a blockchain (Banerjee, 2018; Pytel et al., 2020; Weking et al., 2020). In contrast, less attention has been paid to the possibility of transferring data from a blockchain into an ERP system (Tönnissen & Teuteberg, 2018). As mentioned in the previous section, providing internal end-to-end traceability is available in enterprise systems through fundamental downstream and upstream analyses, thereby mapping product traceability analysis into the blockchain results in almost redundant IS concepts. The function expands in case several ERP systems and data objects are integrated to represent the end-to-end traceability path of a supply network, which can lead to additional efforts managing the confidentiality of objects between multiple organizations (Pytel et al., 2022; Sedlmeir et al., 2022).

To map more-complex products into a blockchain, product identifiers-objects, such as serial numbers or batches, need to be implemented, which leads to increased complexity in the programming of the smart contract to map a traceability path using organizational structures or developing logic for partially consumed amounts of batches (Pytel et al., 2023; van Dorp, 2003). To limit the coordination effort and management of objects, we choose the highest level of abstraction that can be expressed by a traceability path of organizations we define as **system**. A system object represents a list of enterprise systems gathered from various organizations and the flow of a product through the supply network. Systems objects, therefore, must be merged in production orders inside the ERP system to prevent complex operations on the blockchain. However, the list of organizations is merged on the blockchain. Further objects necessary to achieve a coherent flow of tokens in Ethereum are the use of a **Contract** (e.g., 0x123 and 0x124), a **TokenID** (e.g., ID1, ID99), and the transfer of a token **from** one **Owner to** another (e.g., from USID n to USID n+1) (**DF2**: Blockchain ERP Integration through Objects: TokenID, Contract, FROM/TO OWNER, System).

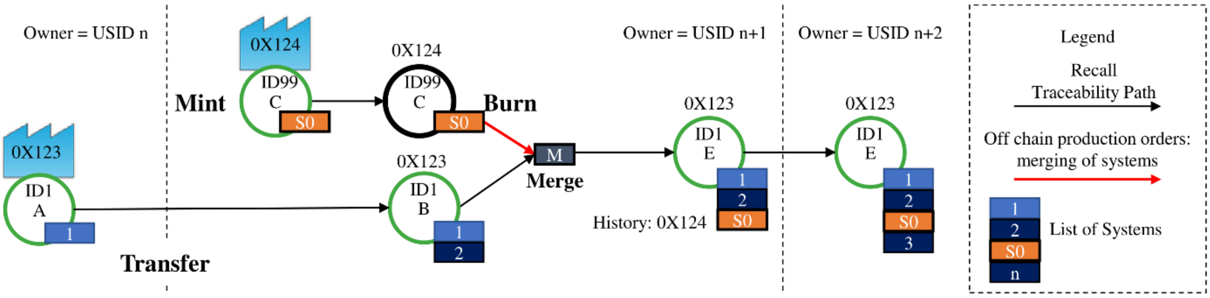

Figure 4-III. Token flow and collection of organizations

To connect enterprise systems with EVM-compatible blockchains, their unique identifier, the contract address, and the TokenID combined must be recorded in a movement table of an enterprise system. In addition, the TokenID must be assigned to a serial or batch identifier, which is pulled from output/finish material after final confirmation of a production order (see make/merge and TokenID 1). An example of Figure 4-III is shown in exemplary Table 4-III.

As a result, we show the technical feasibility of integrating a token's flow in a movement table of a traditional enterprise system, which, however, is limited to an intra-organizational perspective. Therefore, we extend the concept to multiple organizations and customers.

4.4.1.2 Iteration 2: Managing the complexity of network objects

In this iteration, we zoom out of a single ERP system and develop an inter-organizational perspective, as defined in the previous section.

SCOR Event	**Product ID and Identifier**		**Token ID**	**Contract**	**Systems**	**Owner=System From/To**
Source	Raw-B	1	1	0x123	1, 2	USID 2
	Raw-D	2				
	Raw-C	3	99	0x124	S0	USID S0
Make (**Merge**)	Finish-E	4	1	0x123	1, 2, S0	USID 3
	Raw-B	1	1	0x123	1, 2	USID 3
	Raw-D	2				USID 3
	Raw-C	3	99	0x124	S0	USID 3
Deliver	Finish-E	4	1	0x123	1, 2, S0, 3	USID 4

Table 4-III. Modified movement table of a single ERP system

A Unique System Identifier (USID) shows a possible technical object as the highest level of abstraction to identify an ERP System (Pytel et al., 2022). In our concept, we adapt the idea of defining a traditional enterprise system as a token owner to connect multiple enterprise systems, which can be transferred to a customer at the end of the product flow. Therefore, Figure 4-IV describes the possibility of this token flow without the need to map and create standards for organizational structures (e.g., workstations, plants) of heterogenous ERP data models. The challenge in this approach is to identify the enterprise systems and organizations that will participate in the supply network system and connect them to smart contracts that allow them to mint tokens. We have also considered more-complex IT landscapes, where an organization can operate multiple ERP systems (see **USID 2 and 3 of Organization 2**). In the following case, even a subcontractor can participate in the system, depending on the product flow, if they are assigned to a smart contract (see **SC 0x124**). For systems to be merged correctly, organization 2 needs to maintain the **S0** of the subcontractor in **USID 3.**

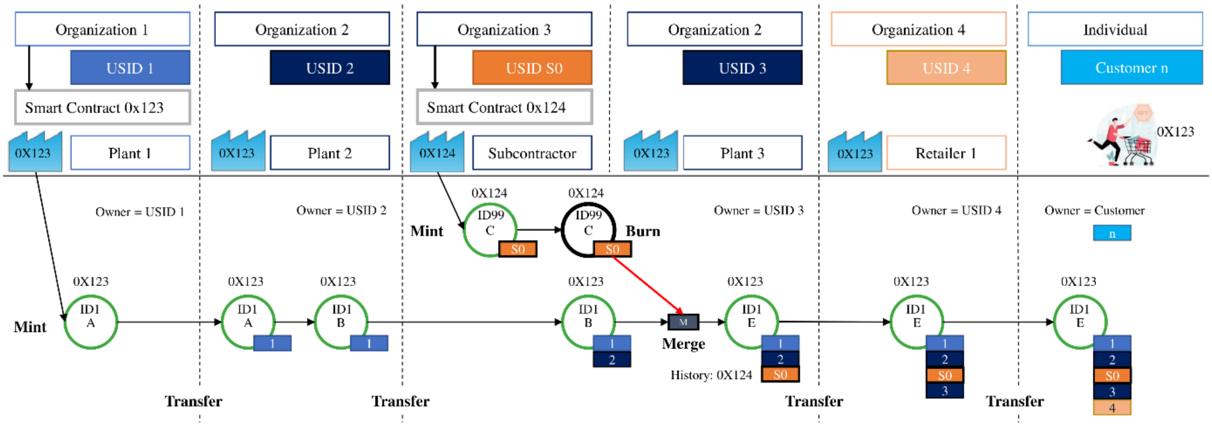

Figure 4-IV. Organizations, Systems, and Smart Contracts of ReCoBridger

Ethereum allows developers to develop and implement smart contracts on the Ethereum blockchain, a distributed computing platform. The defining features of Ethereum include the ability to generate and trade tokens, which are virtual assets representing a unit of value employed for various purposes, including transactions, administration, and utility functions within decentralized applications. The Ethereum protocol has introduced several token standards since its launch, defined by Ethereum Improvement Proposals (EIPs). %Developers submit these proposals for community review and approval. This section discusses the existing token standards on Ethereum and their respective EIPs.

ERC Standard	Status	Title	Purpose
ERC20	Final	(Fungible) Token Standard	A standard interface for tokens
ERC777	Final	(Fungible Payment) Token Standard	Defines standard interfaces and behaviors for token contracts
ERC721	Final	Non-Fungible Token Standard	Standard for non-fungible tokens
ERC1155	Final	Multi Token Standard	Multiple tokens in a single contract
ERC1363	Final	Payable Token	Executes code after a transfer or approval
ERC725	Draft	General data/key-value store and execution	Provides an interface for a smart contract-based account with attachable data key/value store
ERC884	Stagnant	DGCL Token	A token that is Delaware General Corporation Law–compliant
ERC1337	Stagnant	Subscriptions on the Blockchain	Monthly subscriptions for decentralized applications

Table 4-IV. Existing Ethereum Token Standards (Ethereum Foundation, 2023)

Table 4-IV summarizes the EIPs for token standards on the Ethereum blockchain. These standards offer a range of features and functionalities, such as standard interfaces for tokens, non-fungible tokens for unique assets, multi-token standards for managing multiple tokens in a single, smart contract, payable tokens that enable more complex interactions, and a smart contract-based account structure. These standards have different statuses; some are being widely adopted and finalized, while others are still being drafted or are stagnant.

None of the existing token standards listed in Table 4-IV fully meet the requirements for our new recall communication token. While some standards, such as ERC721, allow users to create unique tokens, they do not provide the necessary functionality to trace previous manufacturers and notify all previous holders simultaneously. While ERC1363 and ERC777 offer more complex interactions between tokens and smart contracts, they do not address the specific needs of recall communication, such as product and recall states and a list of organizations that manufactured the product. Therefore, creating a new token standard is necessary to achieve the goal of our new token, which is to provide a comprehensive recall communication solution.

While the ERC1155 does not provide us with everything we require, it is an excellent starting point for a few reasons. The first reason is interoperability, as the standard allows for multiple token standards within one smart contract. This also allows for extensibility, such as adding fungible tokens to this system in the future. Second are batch operations that allow us to mint and send multiple tokens at once, making the system more efficient in production. We acknowledge that taking the ERC721 standard as a basis would have been a good option, too short of the before-mentioned convenience features.

The token must be stored on a system that is available to all manufacturers and customers (**DF4**: Interorganizational blockchain-based data storage). Second, the token must implement a standard interface to transfer it from organization to organization, organization to customer, and customer to customer (**DF3**: Recall tracing and product state extension of the token). Third, all manufacturers must be known to create a history of previous manufacturers that is then used for the recall process (**DF6**: Smart Contract Token Ownership Tracing History).

4.4.1.3 Iteration 3: State definition and execution for customer-manufacturer recall procedures

We conceptualize established procedures that are recognized and performed in manufacturing facilities to provide simple solutions that humans can process visually and intuitively. For this purpose, we rely on the visual management concept known as ANDON (Santos et al., 2014). It is characterized as the most typical sort of light used in visual control applications and consists of three distinct colors – red, yellow, and green – which each express a distinct meaning (Ortiz & Park, 2011).

To reflect the current state of the product and the recall process, we have implemented three products and three recall states (see Figure 4-V). The product state "OK" is used by default, and "On Hold" is set once a customer announces a product is defective (**backward recall**). This also sets the recall state for this product for all manufacturers to "Check Requested." Every manufacturer can set the recall state to "Checked OK" or "Checked NOT OK." If one manufacturer sets the recall state of a specific TokenID to "Checked NOT OK," the product state changes to "NOT OK." If every manufacturer sets the recall state to "Checked OK," the product state changes to "OK" again. Figure 4-V shows the product and recall states with the example of one product and its manufacturer recall states by manufacturers' object systems. The product state is "NOT OK" as manufacturers 2 and S0 have set the recall state to "Checked NOT OK" (**DF7**: Manufacturer recall state management; **DF5**: Customer product defect announcement). All manufacturers can also directly set the product to "Checked NOT OK," initiating a **forward recall** that notifies all customers with this token of the defective product (**DF6**: Manufacturer product defect announcement). Lastly, the customer can also provide voluntary information about his health state by using the recall states where "Checked NOT OK" means the customer's health is impacted. The majority of product safety risk assessments focus on human bodily injury or health (Olsen & Borit, 2018). As a result, this data is compliant with the necessity to identify the severity and number of impacted humans (e.g., private customers) in the context of risk assessments (Ortiz & Park, 2011). The blockchain technology offers furthermore a supporting wallet-to-wallet communication to provide customers with additional and individual information from manufacturers about how to proceed with "NOT OK" products.

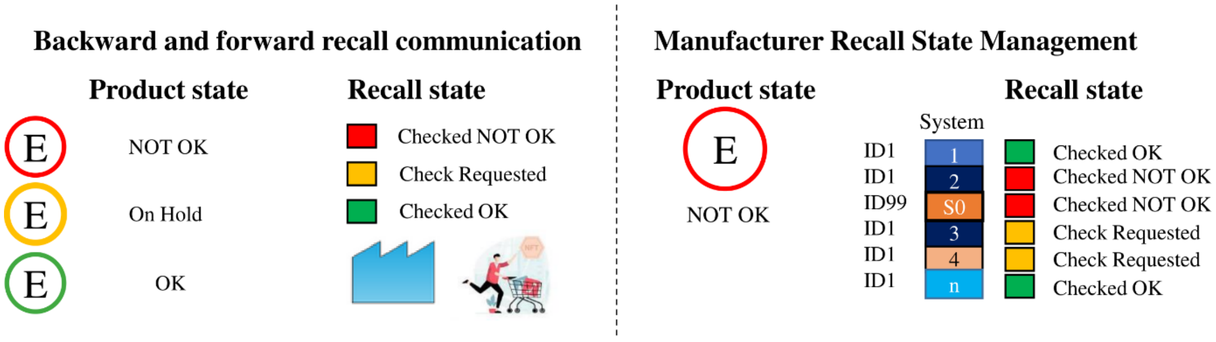

Figure 4-V. Recall Communication and State Management

We provide our prototype on the Polygon Testnet Mumbai, and the interface specification and the reference implementation is in permanent decentralized storage. We also want to emphasize that the files are always available on other IPFS gateways with the same Content Identifiers (CIDs).

Prototype:
https://mumbai.polygonscan.com/address/0xb5e0c4721e7e1b66CE58755996467A0E0345b0dA\#code

Interface:
https://gateway.ipfs.io/ipfs/Qmb1iJf3qzvzLYcsPg3b6mTbz13Tgqj44PK4sX2tHmyPAW

Implementation:
https://gateway.ipfs.io/ipfs/QmNauDrDuuo8mcc9YWS6sYdBs6Q3Zxx2qesXvfmjfvPgjk

4.4.2 Mapping design features to design principles

Design principles are abstractions that describe prescriptive knowledge and should be written so that their recipients can quickly grasp them to ensure their utility. For this purpose, we use a mapping diagram to connect the design features to the design principles (Möller et al., 2020). Finally, the design principles are also subsequently linked to the design requirements. Figure 4-VI describes the aim, context, and mechanism according to the recommendations for formulating design principles (Gregor et al., 2020). The authors further divide into different roles, which we have illustrated through different colors and titles, highlighting possible features with which the respective role will have points of contact in the ReCoBridger IS.

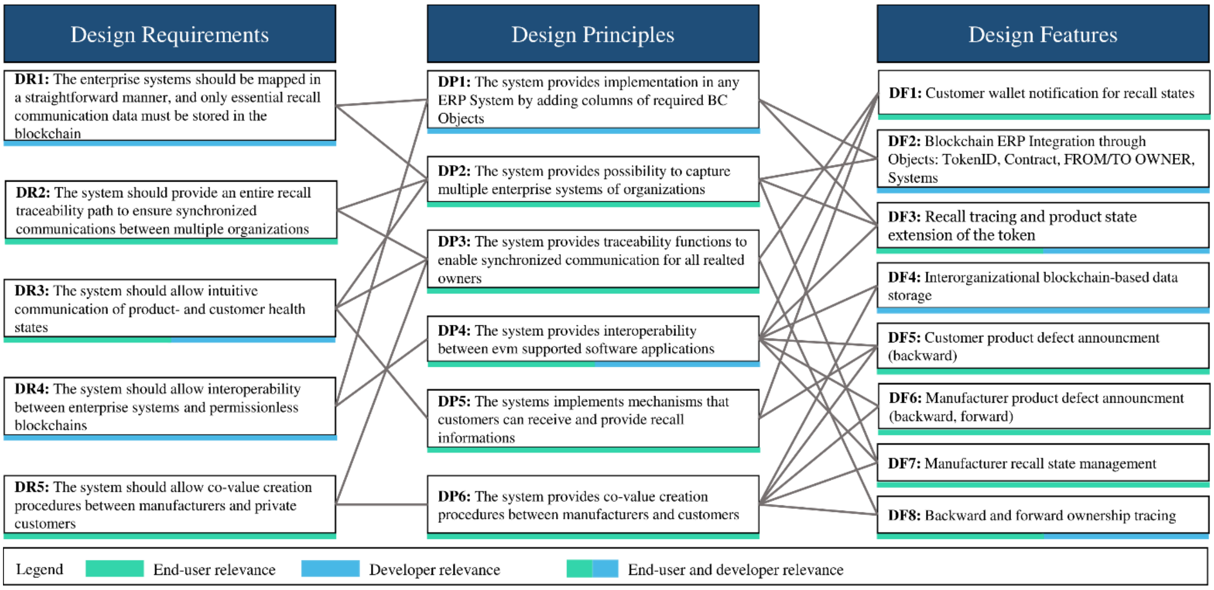

Figure 4-VI. Mapping of Design Requirements, Design Principles, and Design Features

DP1 integrates any ERP system by extending existing data models of required blockchain objects (DF2) and recall tracing (DF3), promoting seamless communication between ERP and blockchain systems. **DP2** captures multiple enterprise systems and analyzes historical owners (DF7) using blockchain-ERP integration (DF2) and recall tracing (DF3), fostering cross-organizational collaboration in recall processes. **DP3** enables traceability functions with customer wallet notifications (DF1) and backward and forward ownership tracing (DF8) to ensure synchronized communication for all related owners. **DP4** provides interoperability between EVM-supported software applications using recall tracing (DF3), customer wallet notifications (DF1), inter-organizational blockchain-based data storage (DF4), customer product-defect announcements (DF5), manufacturer product-defect announcements (DF6), and manufacturer-recall-state management (DF7). **DP5** implements mechanisms that allow customers to receive recall information (DF1) and announce product defects (DF5), promoting active customer participation. Lastly, **DP6** fosters co-value creation procedures between manufacturers and customers using inter-organizational data storage (DF4), customer and manufacturer product defect announcements (DF5, DF6), manufacturer-recall-state management (DF7), and backward and forward ownership tracing (DF8).

4.4.3 Reusability of design principles

We conducted a qualitative evaluation to check whether experts found the abstracted design principles reusable. We have acquired eleven participants who are experienced in the tracing of security-relevant products. As a prerequisite, this interviewee should be familiar with cross-location product traceability, as well as the necessary product grading in the context of customers. We interviewed four senior developers with extensive experience in Blockchain-based systems on the technical side. Table 4-V contains a detailed description of all 14 interviewed partners. The interviews lasted around one hour each.

Id	Background and Job Title	Domain
1	Business - Supply Chain and Quality Control	Manufacturing
2	Business - Quality Control	Manufacturing
3	Business - Supply Chain	Manufacturing
4	Business/Technical - Supply Chain and Quality Control	Manufacturing
5	Business - Supply Chain and Quality Control	Food
6	Business - ERP Consultant	Food
7	Technical - Senior ERP Consultant	Food
8	Business - Supply Chain	Manufacturing
9	Business – Senior Quality Control	Manufacturing
10	Business - Quality Control	Manufacturing
11	Chief Technology Officer	Technology
12	Senior Software Engineer	Technology
13	Senior Software Engineer	Technology
14	Software Engineer	Technology

Table 4-V. Overview of interviewees

We followed the propositions for evaluating DSR-based design principles (Iivari et al., 2021). The authors propose for the evaluation to use criteria accessibility, importance, novelty and insightfulness, agency and guidance, and effectiveness. We asked participants to rate the constructs through several questions on a 5-point Likert scale (1 = strongly disagree, 5 = strongly agree). We conducted the evaluation in combination with an expert interview and an online survey. Figure 4-VII illustrates the corresponding results. The questionnaire was designed according to the (Iivari et al., 2021) questionnaire template.

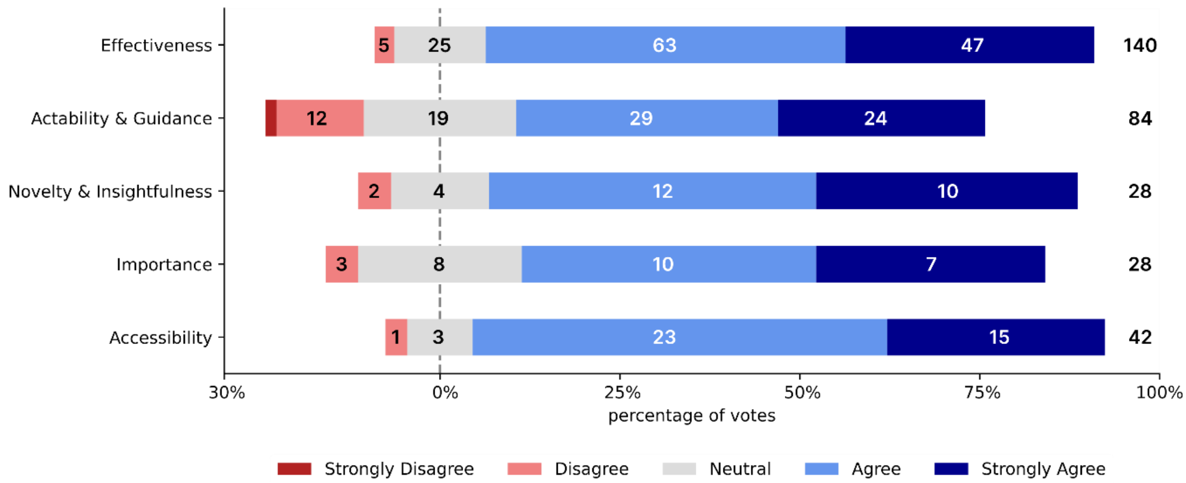

Figure 4-VII. Results of the Expert Interview Questionnaire

The results show positive feedback from the experts that we show in Figure 4-VII, and have not resulted in any changes to the formulations. Therefore, we consider the design principles presented in Figure 4-VI to be ready to use.

4.5 Discussion

Traditional enterprise systems continue to be the backbone of the information society and the foundation for developing internal traceability for manufacturers. However, due to their history, traditional enterprise systems like ERP are more suited to vertical than horizontal integration (Sunyaev et al., 2021). Another challenge in designing an IS is the creation of accepted standards across enterprise systems and various software providers (Pytel et al., 2022). A trade-off can avoid conflicts between different **TOE** dimensions while combining already implemented and novel technologies. This trade-off can prevent conflicts and competition between different human perspectives while enabling structured technological innovation decision-making. Following (Chatterjee et al., 2021; Tönnissen & Teuteberg, 2018; Tornatzky et al., 1990), we will discuss the organizational, technical, and environmental dimensions of the

ReCoBridger IS below. In each dimension, we pose a research question that can be answered specifically and in collaboration with researchers and practitioners in the future.

4.5.1 Technical Dimension (T)

Data Privacy. Information required for the recall process is persistently stored on the blockchain and accessible to all actors. Such transparency might enable malicious entities to infer data about recalls associated with specific manufacturers, potentially harming their reputation. It's noteworthy, however, that the blockchain doesn't retain details about the products (e.g. productID, identifiers); such details are stored solely in the individual manufacturer's enterprise systems. Still, by examining the associated wallets, manufacturers might gain insights about their product users.

Scalability. Performance testing has yet to be conducted, and we haven't delved into the scalability nuances of various blockchains. Given that our system is tailored for any EVM-enabled blockchain, its performance and scalability will vary significantly based on the chosen blockchain for deployment. For instance, deploying on the Ethereum mainnet might lead to anticipated challenges such as elevated transaction fees or extended confirmation durations, rendering scalability on this network financially unviable. However, on a Layer2 blockchain or an application-specific blockchain, scalability is likely to be cost-effective.

RQ: Which features would be required by the IS to reach mass adoption?

4.5.2 Organizational Dimension (O)

Culture and Structure. The provision of concepts and prototypes serves, first and foremost, the open culture of an innovative and cooperative manufacturing company. The ability to test components and reflect ideas firsthand before putting them into productive use, provides the opportunity to identify a value for one's own employees (humans), and strategic supply network participants (Liker, 2021). It offers the chance to get in touch with new technologies, that reduces obstacles (e.g., resistance to change) and allow an open dialogue to a redesign of a traditional enterprise system like ERP. Furthermore, because IS are not just technologies but also the outcomes of their designers and users, human integration is essential as it will always be a part of value creation (Pytel et al., 2022).

Our design approach is based on the internal communication procedures of a lean management manufacturing philosophy, who's objective is to identify and provide customer value while establishing simple procedures (Lorenz et al., 2019). We therefore relied on the visual management of internal communication processes which supports decision-making for small, medium and large businesses. Finally, our findings for conceptualization provide a simpler and less expensive entry point for businesses with limited IT resources, reducing the effort and, thus the costs of conceptualization and implementation.

RQ: Can communication systems like ReCoBridger change the culture and openness to collaborate?

4.5.3 Environmental Dimension (E)

Industry Characteristics. Standards for monitoring and regulating industries for the usage of permissionless blockchain-supported IS have not been identified in our study. Our research examined authority guidelines, industry standards, and enterprise provider procedures for conducting recalls.

Typical product identifiers like batch or serial numbers serve for the identification of physical assets in many industries and are recommended by authorities for recall processes (Commission et al., 2022; Official Journal of the European Union, 2004). A simple and in the network unique TokenId is not widely used yet. However, it can be linked to the informal communications structure and the products of the manufacturers enterprise systems. This likelihood informal linking structure, not owned by a single authority and implemented in a decentralized manner, addresses transparency concerns of organizations and can increase acceptance of an IS from a manufacturers perspective.

Trading Partners. In the discussion of technological innovation decision-making, the study of Chittipaka et al. (2023) links rivalry and trading partner pressure as relevant latent variables. They are described through items that impress that new technologies are the solution for business processes but hardly show any relation to enterprise systems or blockchain data. As we demonstrated, traditional enterprise systems already provide basic functionality regarding internal traceability analysis. However, bounded ERP systems do not support a customer-centric co-value creation approach with private customers. As a result, we regard the ReCoBridger IS as an instrument for enabling novel recall processes, such as improved recall communication between trading partners, rather than as a solution. Innovative decision-making, therefore, is not pushed by environmental external pressures. It's rather intended to change currently isolated subsystems into a modern dialogue of co-value creation path between manufacturers and customers.

RQ: How can customers be incentivized to join the co-value creation with the manufacturers?

4.6 Contributions

Our research makes several contributions to the literature. First, we present a conceptualization of a new token standard to the Ethereum request for comment (ERC) standard for recall communication, which can potentially improve the efficiency and effectiveness of the recall process. Second, we introduce a new IS that can be used for recall communication, incorporating the proposed token standard and other relevant features. Third, we comprehensively discuss different token standards for recall communication, highlighting their strengths, weaknesses, and extensibility. Fourth, we provide design principles that are highly reusable for practitioners.

Fifth, we offer an IS–centered modeling technique to improve coordination efforts. It offers technical and social aspects to holistically capture the complexity of multiple organizations and their IS in supply networks. Sixth, we contribute to the discussion of subsystems and information related to IS artifacts. Finally, we map the requirements of enterprise goods to public ledger software, specifically EVM, to demonstrate the feasibility and practicality of the proposed system. We also add a network design, including organizational and technical aspects, which can be used to implement the proposed system.

Our paper makes several contributions to practice. We propose implementing a new token standard that can improve the efficiency and effectiveness of recall communication for enterprise goods. Second, we explore how blockchain technology can be used to connect enterprises with customers to directly inform and involve them in the recall process, thereby improving communication and collaboration. Customers can thus receive faster and more personalized case-related information (e.g., measures before and after the use or consumption of a product) from multiple manufacturers. Third, we investigate how blockchain identifiers can be integrated minimally and non-invasively into existing enterprise systems to enable better tracing and monitoring of recalled products. Finally, we reuse the terminology of backward and forward traceability, which involves propagating important recall information from the product user back to the manufacturer. %enabling them to identify and address issues related to the recalled product correctly.

4.7 Limitations and Outlook

This research has limitations in five important areas: decentralized management, data privacy, incentives for using the system, special cases, and middleware. First, with the current setup, there is a need for a single orchestrator that helps all involved parties to update their software and set up the smart contracts. Second, data put into the system is publicly available for everyone in real-time, allowing outsiders to gain business intelligence. Third, the system as is does not offer real-world incentives to customers for using the system; More research is needed to design an incentive system. We have not designed the artifact to handle cases like products that have no identification number (e.g. serial number). Software that connects customers wallets with the obtained products is not designed in our artifact.

Future research should extend the scope of the system using a Decentralized Autonomous Organization (DAO) that consists of all smart contracts used to issue recall tokens and a registry of all available contracts that manage these tokens. This DAO would allow creators of ecosystem software to better support the recall tokens. Additionally, research should expand the data privacy of the proposed system by investigating the incorporation of Zero-Knowledge proofs and on-chain encryption. These approaches would allow for the secure and private sharing of sensitive information between parties. To encourage customer participation, incentives such as token-based rewards or discounts could be investigated.

Moreover, our research does not consider cases like joint production and recursive processes, and the middleware and connection of multiple ERP systems are out of this paper's scope. We focus on communication between the manufacturer and the customer rather than on the manufacturer's recall management. We acknowledge that customers are responsible for securing their wallets with ReCoBridger.

4.8 Conclusion

In this study, we investigated innovative approaches to augment existing recall communication processes between manufacturers and end customers by examining the integration potential of traditional technologies, such as ERP systems, with blockchain and token techniques. We formulated two research questions and utilized an IS Artifact to address these queries.

In the first research question, we investigated strategies to involve customers with manufacturers effectively. We determined that providing customers with access to a wallet enabled them to participate in backward and forward active recalls via interaction with the product and recall states, thus making valuable contributions and supporting manufacturers during recall situations.

In the second research question, we explored the design principles that can facilitate efficient recall communication between customers and manufacturers, supported by an interoperable, integrated ERP-blockchain-based IS Artifact. Our methodical research approach enabled the development of several design principles, which practitioners have confirmed possess high reusability.

Additionally, we examined how a token-based approach, leveraging our proposed ReCoBridger IS, could enhance recall procedures and foster co-value creation between manufacturers and customers. Through a thorough analysis and extension of existing ERP data models and ERC standards, we demonstrated the feasibility of designing and integrating a token-based approach across multiple organizations, capturing the complexity of inter-organizational perspectives.

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5 Essay IV: A Network Analysis of Decentralized Autonomous Organizations

Abstract

Decentralized Autonomous Organizations (DAOs) are multifunctional systems that mediate transactions between humans and blockchains or operate entirely autonomously. While considerable attention has been given to their organizational structure, their characteristics as online communities remain largely unexplored. This study aims to fill this research gap by analyzing a dataset comprising 31,002 DAOs, 220,960 proposals, 51,987,413 votes, 154,087,070 token ownerships, and 46,695 historical governance token prices. The research addresses several key aspects. First, it confirms the presence of the 90-9-1 rule. Second, it highlights the unequal distribution of voting power through a deciding voter analysis. Third, it validates the scale-free network properties by fitting a power-law function to the degree distribution of DAO memberships and proposal participation suggesting the existence of influential nodes within the network. Last, the study indicates that the diffusion of information is uninfluenced by the level of connectedness among voters, as determined by their shared memberships in DAOs.

Keywords: Decentralized Autonomous Organizations, Online Communities, Network Analysis

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5.1 Introduction

Decentralized Autonomous Organizations (DAOs) are multifunctional systems, functioning either to mediate interactions between humans and blockchains or operating as entirely autonomous systems with capabilities for storage, transaction of value, notary (voting) functions, autonomous execution, and a decentralized environment (Hassan & Filippi, 2021; Rikken et al., 2023; Schillig, 2021).

Decisions within DAOs are made through online voting mechanisms known as proposals, where the voting power is most commonly determined by the number of tokens held by a member. These tokens represent a virtual stake in the DAO (Fan et al., 2023).

DAOs consist of three primary pillars: Treasury, governance, and community. The treasury manages all assets and financial resources, governance allocates funds and sets the overall direction, while the community engages in deliberations on objectives and responsibilities, overseeing the governance process (Ziegler & Welpe, 2022).

Each pillar employs different tools to provide value. Treasuries, represented as multi-signature wallets on the blockchain, use tools like Discord and Discourse for communication in the community section. Governance, in many DAOs, is implemented through Snapshot,[13] an off-chain voting portal utilizing decentralized file storage for proposals and votes, offering the advantage of no transaction fees for creating or casting votes.

Snapshot has seen over 230,000 proposals, with DAO treasuries collectively holding $15.8 billion in assets across 2373 tracked DAOs (DeepDAO Ventures Ltd., 2023). The growing interest in DAO governance could be attributed in part to airdrops (Allen et al., 2023) issued to the community.

13 https://snapshot.org/#/

While DAOs have traditionally been viewed as organizations (Hassan & Filippi, 2021; Wright, 2021), we argue that DAOs fundamentally stem from online communities. Drawing from the definition of Preece (2000), online communities comprise *people* interacting socially, *sharing a common purpose*, following *policies* that guide interactions, and utilizing *computer systems* to support and mediate social interactions. These properties align with DAOs, where social interactions occur through provided community-building tools, a shared purpose and policies are defined in governance, and the blockchain serves as the computer system supporting social interactions.

Governance is crucial for all Decentralized Finance (DeFi) protocols operating as DAOs, as the governance proposals effectively decide on the most important applications of blockchain-based systems. They are seen as public good by blockchain users and play an important role in the daily usage of blockchains. Therefore, they are expected to be governed by the community that receives tokens as payment for work or through airdrops (Allen et al., 2023) to participate in the governance. However, this is in most DAOs not the case (Feichtinger et al., 2023; Fritsch et al., 2022), which highlights the problem, why more quantitative research is needed into community networks and voting power distributions.

In the early days of online community research, it was uncertain whether established techniques for analyzing offline communities, such as network analysis, are applicable (Preece, 2000). Subsequently, it became evident that theories applicable to offline communities were also relevant to online communities (Chang et al., 2023; Easley & Kleinberg, 2019; Panzarasa et al., 2009; Yang et al., 2011).

Most online communities relying on user contributions exhibit a participation pattern following the 90-9-1 rule, where 90% read or observe, 9% contribute occasionally, and 1% contribute the majority (Nielsen, 2006). This inequality leads to situations where a small percentage of users produce content consumed by the majority, posing challenges in areas like customer feedback, restaurant reviews, and hotels (Nielsen, 2006).

Applying this participation pattern to DAOs, we hypothesize that 1% create content (proposals), 9% comment on the content (vote), and 90% hold tokens but do not participate in governance. This creates a situation where the decision-making power lies with the 1%, influencing the DAO’s direction, while the 9% approve or disapprove, and the 90% observe. The introduction of Web3 adds a financial incentive for contributors, contrasting with the mainly intrinsic incentives in Web2 (Jin et al., 2015).

This centralization effect is exacerbated by a few wealthy and influential DAO members owning the majority of voting tokens, undermining the perceived decentralization of the 9%. The 90-9-1 rule in DAOs mirror characteristics of scale-free networks, where a few nodes, following a power-law distribution, accumulate a significant number of connections.

The concept of scale-free networks, extensively studied in the context of online communities, gained prominence with the analysis of a part of the internet from Barabasi and Albert (1999). They revealed highly connected hubs and a power-law distribution of link connections. This concept extended to social networks, introducing the term “scale-free network” to describe networks exhibiting a power-law degree distribution. Information diffusion varies depending on the type of network (C. Jiang et al., 2014).

From this discussion, we formulate the following research questions:

- **RQ1**: To what extent can the 90-9-1 rule be applied to DAOs?
- **RQ2**: What is the extent of dominance exerted by deciding voters in the governance process?
- **RQ3**: Do DAOs exhibit the characteristics of scale-free networks?

- **RQ4**: How does the connectivity of a node in the network influence the diffusion of information?

The rest of this paper is organized as follows. In Section 5.2, we present related work covering the 90-9-1 rule, empirical research on DAOs, and network analysis on online communities. Then, in Section 5.3, we introduce our dataset, emphasizing its capabilities and limitations and detail the methodologies for our four empirical analyses—90-9-1, deciding voter, scale-free network, and information diffusion—to address the research questions posed. We outline the methodologies for each analysis first and subsequently present their applications along with the results. Finally, we discuss our findings and draw conclusions in Section 5.4.

5.2 Related Work

The 90-9-1 rule seeks to elucidate participation patterns within online communities, positing that 90% of participants primarily observe without active engagement, 9% contribute sporadically, and 1% are responsible for the majority of content creation (Nielsen, 2006). Empirical examinations of the 90-9-1 rule, as conducted by van Mierlo (2014), Gasparini et al. (2020), Antelmi et al. (2019), validate the overarching trend that a significant proportion of members in online communities predominantly partake in observational activities. However, the precise ratio of passive observers, sporadic contributors, and productive content creators varies among online communities, often deviating moderately from the 90-9-1 ratio.

In the case of X, formerly Twitter, Antelmi et al. (2019) found that 75% of users can be considered silent observers, while 5% are actively contributing. Mierlo studied Digital Health Social Networks within the context of the 90-9-1 rule and obtained an empirical 75-24-1 ratio. A limitation of studies exploring the 90-9-1 rule is that the definition of an active contributor and a silent observer may differ for each study, depending on the specific community. Carron-Arthur et al. (2014) found further evidence that the different contribution groups are mostly not separable, and there is a relatively gradual reduction in contributions between the three user groups. Nevertheless, empirical results support the general hypothesis behind the 90-9-1 rule in the context of online communities.

Network analysis of online communities has been extensively performed in recent years, revealing a substantial body of evidence (Mislove et al., 2007; Newman et al., 2002; Panzarasa et al., 2009; Uzzi & Spiro, 2005) for small-world properties characterized by high local clustering coefficients and small path lengths in subnetworks.

Grandjean (2016) empirically studied the social network X and found structural evidence for the small-world phenomenon. The relevance of specific vertices in the network is quantified by centrality measures such as in- and out-degree, betweenness centrality, and eigenvector centrality. The distributions of the centrality measures of the users of the network approximately follow a power-law distribution. Kim and Hastak (2018) discovered that the in and out-degree distributions of nodes in the networks X and Facebook are highly right-skewed, indicating a general tendency toward social hubs.

While recent research on DAOs is predominantly qualitative (Chao et al., 2022; Kaal, 2021; Kondova & Barba, 2019; Marko & Kostal, 2022; Qin et al., 2023; Sharma et al., 2023), there have been quantitative studies focusing on the properties of DAOs, particularly decentralization, in recent times.

Feichtinger et al. (2023) and Fritsch et al. (2022) conducted analyses on the distribution of voting power within DAOs on the Ethereum blockchain. Fritsch et al. (2022) demonstrate that voting power is significantly centralized, and the dominant parties typically align their votes with the broader community. Feichtinger et al. (2023) computed Gini coefficients for voting power distributions, revealing that almost all coefficients exceed 0.9, indicating a high degree of centralization. Furthermore, they observed that in half of the studied DAOs, three or fewer addresses held most of the voting power.

Goldberg and Schär (2023) present similar findings from their study of voting dynamics in the DAO governing the metaverse platform Decentraland. They scrutinized actors with the most significant voting power and discovered that the voting outcome matched the dominant voter's choice nearly 95% of the time. Additionally, the study revealed that about 45% of DAO grants were approved by a single voter.

Q. Wang et al. (2022) conducted an empirical analysis of 581 DAOs organized on the off-chain voting platform Snapshot, utilizing a dataset similar to that of this paper. Their study focuses on the employed e-voting schemes, infrastructure, project scale, and DAO token usage. Among their findings are centralization threats attributed to contract reliance, IPFS storage, and platform dependency.

The study of scale-free networks in the context of online communities has been undertaken by scholars. Aparicio et al. (2015) investigated the structural properties of X, demonstrating that it can be considered a scale-free network, as the outgoing and incoming degree distributions of nodes in the network approximately follow a power-law distribution. This implies the presence of a few users with a large group of followers or friends, while most users have only a few friends or followers. However, the scientific community is still debating the evidence for the scale-free nature of many networks. In an empirical study, Broido and Clauset (2019) examined nearly 1,000 information networks to determine whether they could be classified as scale-free. They concluded that the social networks they studied are, at most, weakly scale-free.

In a similar context, the diffusion of information has been studied in networks, particularly online communities, referring to the spread of information among interconnected nodes or entities in a network (Kumar & Sinha, 2021). Bakshy et al. (2012) discovered that relationships between people in the network significantly influence the diffusion of information in social networks.

5.3 Methodologies and Their Applications

In this paper, we build upon scholars' previous work in network analysis in online communities by conducting four empirical analyses using the same dataset. The first analysis delves into the 90-9-1 rule, extending to demonstrate the impact of so-called *deciding voters* on DAO governance, and subsequently visualizing the network of DAOs, proposals, and voters. Following that, we examine evidence supporting DAOs as scale-free networks. Finally, we scrutinize information diffusion within DAOs by analyzing members and their shared DAO memberships.

5.3.1 Field data: Snapshot, CovalentHQ, and Coingecko

This section provides an overview of the three data sources combined for our analyses. First, the off-chain voting platform Snapshot "allows DAOs, DeFi Protocols, or NFT communities to participate in decentralized governance" (Snapshot, 2023). On Snapshot, users can create spaces representing DAOs, where voting strategies can be defined for proposals containing governance decisions. Users then vote on these proposals based on the defined voting strategy and mechanism. We obtained the data from Snapshot using their GraphQL API (Snapshot, 2023), resulting in 31,002 Spaces representing a DAO, 220,960 proposals, and 51,987,413 votes on these proposals.

Second, we collected 154,087,070 data points about token ownership from CovalentHQ. This dataset contains precise information about which address owned which token at the block height, representing the voting power of every eligible voter at the proposal creation.

Third, we gathered 46,695 data points on historical prices from Coingecko[14] for all voting tokens, providing us with the voting power in tokens and corresponding dollar values. The disparity in data points between proposals and historical prices is attributed to tokens that are either not listed, have been delisted, or are soulbound, meaning they cannot be traded.

In blockchain-based systems, two distinct types of networks exist: Mainnet and Testnet. Testnets are frequently reset and are exclusively used for testing smart contracts or the blockchain itself. Coins on these networks typically do not hold any real-world value, with the exception of rare cases such as the Goerli Ethereum (Copeland, 2023). Consequently, we exclude all proposals that involve Testnet assets, assuming that spaces using these assets are primarily intended for testing purposes.

5.3.2 Analysis of participation inequality

The problem of participation inequality in online communities is well-known, but its manifestations vary depending on the type of platform users interact with. For instance, on social platforms like X, the majority of users are often considered silent observers, while only a very few actively create content (Antelmi et al., 2019). In software development platforms like GitHub, participation inequality is referred to as the “volunteer’s dilemma” (Gasparini et al., 2020), where a small number contribute code, and the majority silently utilize it. This phenomenon has been previously identified as the “tragedy of the commons,” depicting a scenario where individuals, driven by self-interest, deplete a shared resource, leading to its degradation or destruction (Feeny et al., 1990). In this analysis, we investigate whether participation inequality, specifically the 90-9-1 rule (Nielsen, 2006), holds for DAOs, as we posit they exhibit properties of online communities.

14 https://www.coingecko.com/

To conduct the 90-9-1 analysis, we take three samples. First, we utilize our complete dataset encompassing all DAOs, excluding Testnet data. Second, we randomly sample 10% of DAOs from our dataset. Third, we sample 10% of the top DAOs by voters from our dataset. The inclusion of these different samples adds rigor to our analysis. In this examination, we calculate entries only when we can fully map all proposals, voters, and token holders.

For the analysis, we establish the following definitions:

1. Let $D_{\{t10,r10,full\}}$ represent the top 10% DAOs, random 10% DAOs, and all DAOs
2. Let $P(d)$ represent the set of proposals for a DAO d
3. Let $V(p)$ represent the set of voters for a proposal p
4. Let $T(d)$ represent the set of distinct token holders for a DAO d
5. Let $C(d)$ represent the creator of a proposal d

Using the above, the set V represents the fraction of voters of D:

$$V_{D_{\{t10,r10,full\}}} = \frac{\sum_{d \in D_{\{t10,r10,full\}}} \sum_{p \in P(d)} |V(p)|}{\sum_{d \in D_{\{t10,r10,full\}}} |T(d)|}$$

The set C represents the fraction of creators of D:

$$C_{D_{\{t10,r10,full\}}} = \frac{\sum_{d \in D_{\{t10,r10,full\}}} \sum_{p \in P(d)} |C(p)|}{\sum_{d \in D_{\{t10,r10,full\}}} |T(d)|}$$

Let $T'(d)$ represent the set of distinct token holders for a DAO d excluding $V(p)$ and $C(p)$ such that:

$$T'(d) = \{t \mid t \in T(d) \land t \notin \mathrm{V(d)} \land t \notin \mathrm{C(d)}\}$$

Then, the set L represents the fraction of lurkers (token holders) of D:

$$L_{D_{\{t10,r10,full\}}} = \frac{\sum_{d \in D_{\{t10,r10,full\}}} \sum_{p \in P(d)} |T'(d)|}{\sum_{d \in D_{\{t10,r10,full\}}} |T(d)|}$$

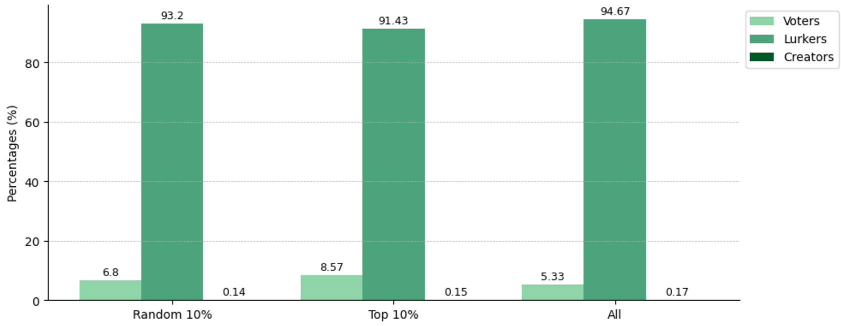

Figure 5-I. Distribution of voters, lurkers, and creators across the samples

From Figure 5-I, we deduce that the 90-9-1 rule applies to DAOs. However, with a 95-5-1 distribution, creators are also considered voters.

5.3.3 Analysis of deciding voters

Next, we analyze the distribution of voting power within the 5.33% of voters in DAOs. Feichtinger et al. (2023) and Fritsch et al. (2022) have empirically examined voting power distributions in DAOs, focusing on datasets other than the one we are using. They observed a highly centralized voting power distribution in DAOs. Our objective is to either corroborate or challenge their findings by leveraging our extensive dataset in this analysis.

We employ a dataset comprising 31,002 DAOs, 220,960 proposals, and 51,987,413 votes to unveil power distribution within DAOs. Initially, we filter it based on the following criteria: a minimum of five proposals per DAO, at least five votes per proposal, exclusion of DAOs on the Testnet, and ensuring DAOs and proposals are not flagged by Snapshot. This filtering leaves us with 47,048 eligible proposals and 45,592,752 votes.

Continuing, we ascertain the voting power of each voter on every proposal and calculate the total voting power for each proposal by summing up individual voting powers. Using this total voting power, we compute the relative voting power as a percentage for every voter on every proposal.

Subsequently, we arrange the voting power for each proposal in descending order and calculate a running total of the voting power. For instance, in a proposal where voters possess relative voting powers of [40%, 30%, 20%, 10%], their corresponding running total voting powers would be [40%, 70%, 90%, 100%]. Following, we identify the count of voters required for each proposal to surpass 50% of the total voting power. In our example, this count is 2, and we refer to them as the deciding voters.

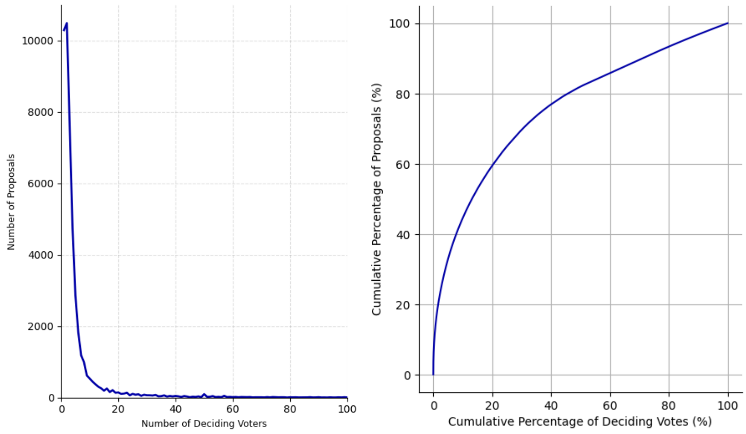

Figure 5-II. Number of deciding voters based on the number of proposals, presented as absolute counts and percentages

Figure 5-II illustrates that in 86.3% of proposals, fewer than 10 voters determine their outcome. This indicates a concentration of voting power within DAOs among a select few. While this observation would be adequate if we were exclusively analyzing large DAOs, Figure 5-II contextualizes this discovery by revealing that less than 20% of all votes influence over 60% of all proposals. However, considering the presence of non-negligible proposals with a limited number of votes, we must align the count with the total number of voters for each proposal, presenting the distribution of deciding voters as a percentage. This corroborates the findings of Feichtinger et al. (2023), who observed similar results in their restricted dataset.

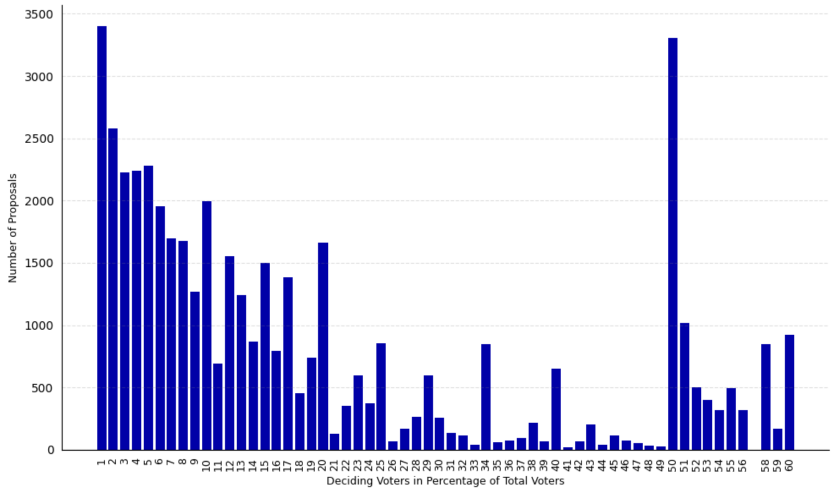

Figure 5-III. Relationship between the share of deciding voters and the number of proposals

Figure 5-III illustrates this relationship. The x-axis represents binned percentages, indicating the proportion of total voters that constitute deciding voters. The chart reveals two key insights. Firstly, there are numerous proposals where less than 10% of the voters wield over 50% of the voting power. Moreover, almost 3,500 proposals are determined by less than 1% of the voters. Secondly, the chart highlights proposals that are not influenced by a minority but instead, decisions are made with equal voting power, as indicated by the significant number of proposals at 50%. Upon closer examination, we identified that these proposals employ a one-vote-per-address method implemented through a whitelist, ERC721 (Non-Fungible-Token, NFT), or a single ERC20 token.

5.3.4 Analysis of connections between DAOs, proposals, and voters

Until now, we have demonstrated that only 5.33% of all token holders participate in voting. Within this subset, the distribution of voting power is highly unequal, with 45% of the votes determining 80% of all proposals. In the subsequent analysis, we delve into the observation that not only is the total voting power centralized, but the monetary value of this voting power is also highly concentrated.

The following graphs illustrate the connections within our combined datasets. Each colored circle represents a proposal, with each DAO having its distinct color, while the black dots represent voters. The size of each circle is determined by the exercised total voting power in dollar value, with the dollar value being taken from when the proposal was created. Figure 5-V showcases the connections through exercised votes, while Figure 5-IV represents all potential votes.

Both figures highlight the strong interconnectedness between most DAOs. However, some DAOs exhibit voters without connections to other DAOs, a phenomenon possibly explained by airdrop farming or privacy practices. The presence of large DAOs and their affluent token holders is evident in both figures. Further investigations are imperative, not only into the connections between voters and multiple DAOs but also into how they acquired their governance tokens, to draw a clearer picture of the connections within the DAO ecosystem.

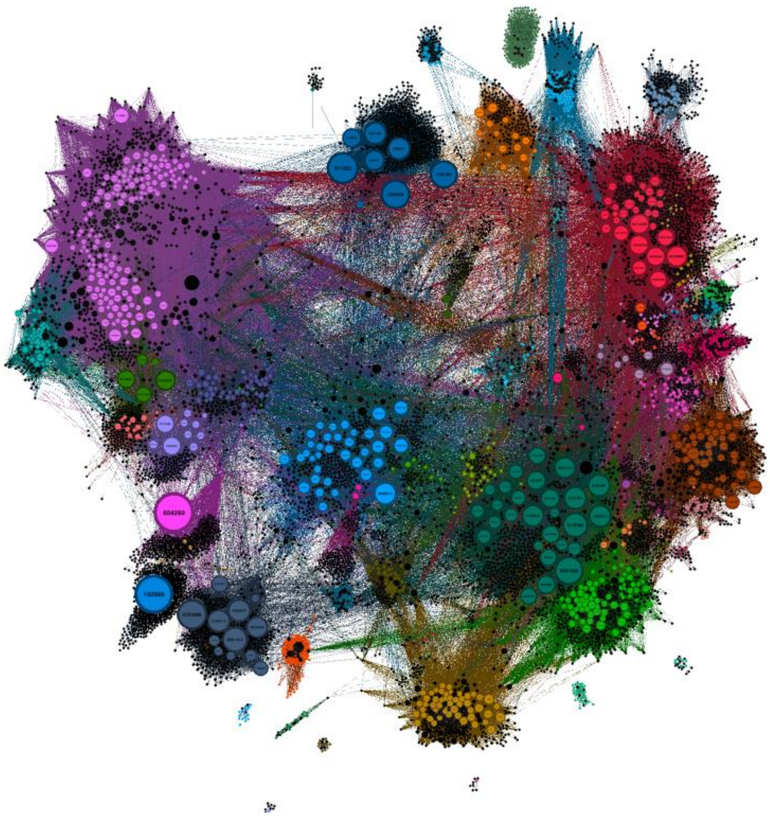

Figure 5-IV. Snapshot's DAO network with all potential voting edges

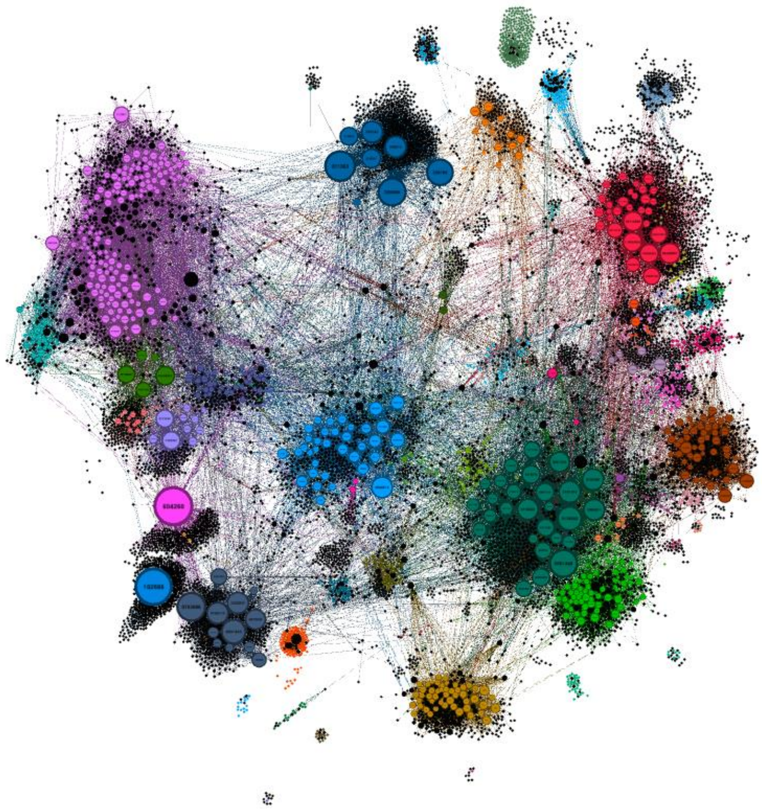

Figure 5-V. Snapshot's DAO network with all asserted voting edges

5.3.5 Analysis of scale-free network properties

Scale-free networks are characterized by a degree distribution that conforms to a power-law distribution, and they are believed to emerge spontaneously in diverse and unrelated domains. Examples include technological realms such as the internet, social networks involving academic references and collaborations among film actors, and biological systems like protein interaction networks (Broido & Clauset, 2019). A fundamental concept considered the underlying principle of a scale-free network is the preferential attachment rule, stating that during network creation, the probability that a node gains a new connection is proportional to its current degree (Barabási, 2009).

Our objective is to verify the presence of scale-free networks in online communities, focusing on the structure of DAO membership and proposal sizes. We utilize power-law functions to gather evidence for the emergence of scale-free networks in our DAO datasets, relying on goodness-of-fit metrics to quantify the results. Subsequently, we fit selected statistical distributions and assess their goodness of fit using a well-known statistical test. Each distribution is evaluated based on the fit visualization and the test, aiming to prove or disprove the hypothesis that the data is sampled from a power-law distribution, essentially determining if the network can be described as scale-free (Broido & Clauset, 2019).

For our analysis, we curated two datasets:

1. DAOs and their active voters: In this dataset, individual DAOs and voters serve as nodes, with edges representing the act of voting within a DAO. The degree distribution indicates the presence of a small number of highly popular DAOs, with 924 DAOs having a maximum of 5,000,000 active voters.
2. Proposals and their voters: In this dataset, individual proposals and voters are nodes, and edges represent the act of voting on a proposal. The degree distribution suggests the existence of a small number of highly popular proposals, with 45,932 proposals having a maximum of 600,000 votes.

Following, we applied various curves and distributions to the datasets mentioned above:

1. Power-law function $P(x) = Cx^{-\alpha}$: This function is employed to model datasets where a small number of items are clustered at the top of the distribution, dominating the majority of resources.
2. Power-law function with exponential cutoff $P(x) = (ax^{-\alpha} + c)e^{-dx}$: Since the power-law function exhibits a “heavy tail,” meaning it converges to zero more slowly than exponential functions, the exponential multiplier is introduced to ensure a more exponential curve beyond a certain point, enhancing the fit to the noise in the tail.

3. Power-law distribution $f(x, a) = ax^{a-1}$: This continuous random variable is also known as the Pareto distribution and is often found to describe processes driven by the rule of preferential attachment.
4. Log-normal distribution $f(x, s) = \frac{1}{sx\sqrt{2\pi}} \exp\left(-\frac{log^2(x)}{2s^2}\right)$: This continuous random variable has a logarithm that is distributed normally. It is identified as describing natural growth processes driven by an accumulation of small changes over time, which are additive on the log scale.
5. Weibull distribution $f(x, c) = cx^{c-1} \exp(-x^c)$: A unimodal continuous random variable widely applied in modeling quality control, biological processes, or reliability analysis due to its flexibility.

To assess the goodness of fit for the curves, we calculated R-squared and Summed Squared Error (SSE). Additionally, we conducted the Kolmogorov–Smirnov statistical test for distributions. The KS test informs us about the likelihood of a sample being drawn from a given distribution. It indicates the similarity of the sample function to the reference distribution, and the p-value helps estimate our confidence in the hypothesis.

The power-law curves show a good fit for both datasets, with high R-squared values and low SSE. Specifically, for the power-law and truncated power-law DAO-member dataset: {0.999532, 182.827804}, {0.998842, 452.691648}, and the proposal-voter dataset: {0.999844, 237,188.711232}, {0.999525, 720,178.488603}. This suggests that both networks may be identified as scale-free.

It seems that no distribution can be confidently described as a likely candidate (KS test with significance level of 95%) from which either dataset can be drawn. In both datasets, the log-normal distribution is the most probable candidate among the three, considering the relatively large p-value (0.000027 for the proposal-voter dataset and a negligible value for the DAO-member dataset) and a visual interpretation of the fit. While the degree distributions seem to be modeled by a power-law function, other distributions may be preferred over the power-law. Previous research has found limited direct evidence for social networks to be scale-free, leading us to believe that mechanisms other than preferential attachment may govern the growth and information dissemination within DAO networks (Broido & Clauset, 2019). In the next section, we explore how information diffusion occurs within DAOs in the context of voting procedures to delve deeper into how these networks evolve over time.

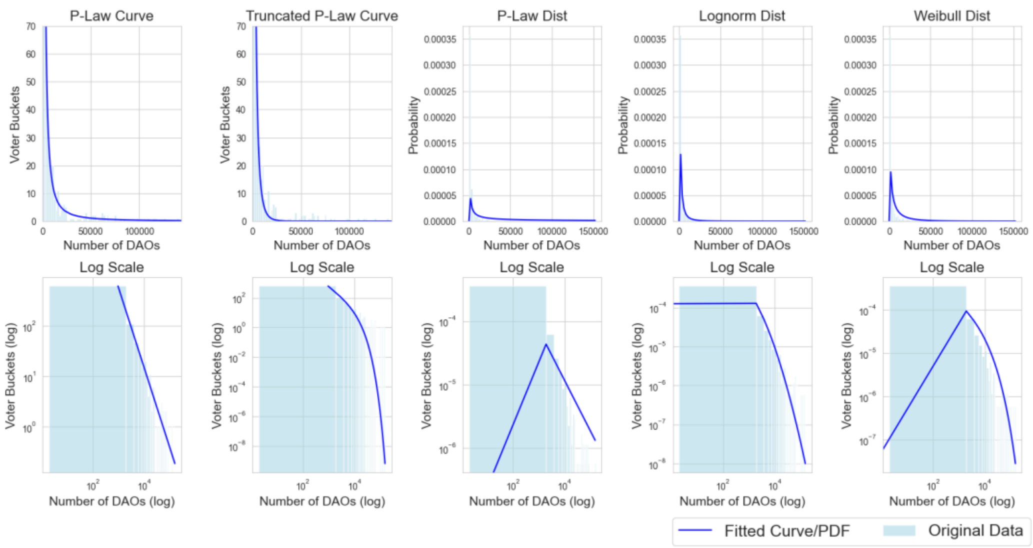

Figure 5-VI. Comparison of curve and distributions fit of DAO-member (linear and logarithmic scales)

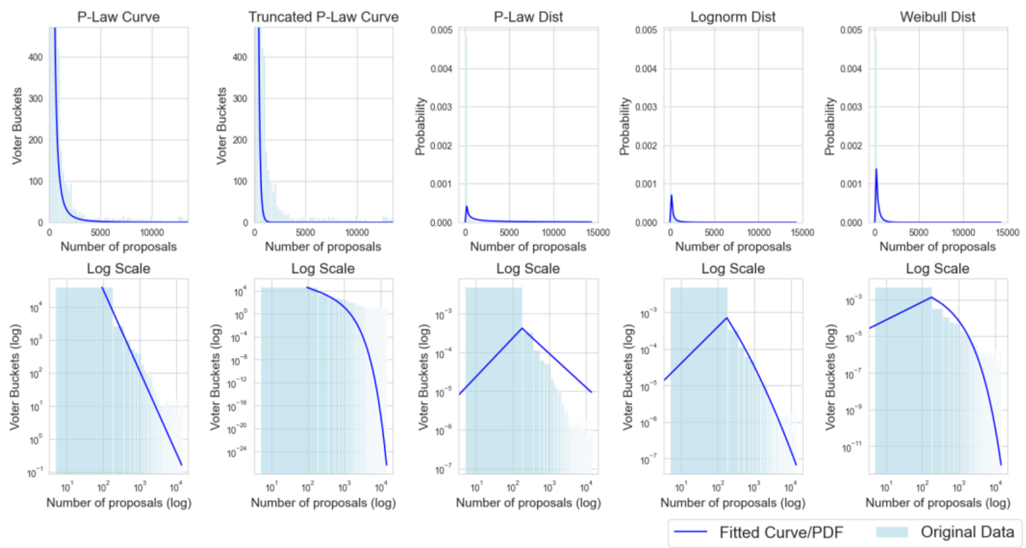

Figure 5-VII. Comparison of curve and distribution fits of proposal-voter (linear and logarithmic scales)

5.3.6 Analysis of information diffusion in DAOs

Information diffusion involves understanding how information spreads within a network (F. Wang et al., 2012). This propagation is quantified by measuring the time it takes for information to reach predefined thresholds, such as 20%, 40%, 60%, or 80% of a network’s critical mass. Network connectivity, referring to the degree of interconnectedness among nodes, plays a crucial role in this phenomenon. Information diffusion has been the subject of extensive research, particularly in the domain of social networks (J. Jiang et al., 2013; Schneider et al., 2009). Attempts have also been made to forecast information diffusion using logistic functions (F. Wang et al., 2012).

In our analysis, voters serve as nodes in our network, and their memberships in DAOs establish connections within the network. We use the Jaccard value, specifically the intersection over the union of DAO memberships, as a measure of interconnectedness among nodes. For instance, if voter X is a member of DAOs $\{A, F\}$, and voter Y is a member of $\{A, B, C, D, E\}$, then the ratio would be $|\{A, F\}|/|\{A, B, C, D, E\}| = 0.2$. To compute the Jaccard value for each voter, we group the dataset by proposals, calculate the Jaccard value for each pair of voters within a proposal, and then take the average of all pairwise Jaccard values for every voter. We apply certain limitations, specifically focusing on proposals with less than 100,000 votes, proposals with more than 10 votes, and DAOs with at least 10 proposals. This filtering leaves us with 19,638,924 votes and 47,704 proposals. This approach aligns with the research proposed by F. Wang et al. (2012), where they analyzed information diffusion based on two metrics: friendship hops and shared interests.

Continuing, we delve into the analysis of voting behavior within DAOs, employing the Cumulative Density Function (CDF). The CDF tracks the progression of votes on a proposal, organizing each vote by its timestamp to create a consistently ascending curve. This curve effectively illustrates the pace at which eligible voters engage in a vote, considering that voting timespans can vary significantly across different proposals. To consolidate this data at the DAO level, where multiple proposals exist, we leverage *relative time*. This metric measures the duration from the start of voting to a specific timestamp, and *normalized hours*, a metric that scales the entire voting period from 0 to 1, covering the span from the beginning to the end.

We categorized the Jaccard indices into intervals [0, 0.25), [0.25, 0.5), [0.5, 0.75), [0.75, 0.99), [0.99, 1.0]. Subsequently, we aggregated the first and second intervals, labeling them as *low*, and the remaining intervals as *high*, effectively splitting the dataset in half at Jaccard value 0.5.

To address our research question regarding how the connectivity of a node in the network influences information diffusion, we explore the time elapsed from the start of voting until various thresholds are reached—specifically, when 20%, 40%, 60%, and 80% of eligible voters have cast their votes. To present aggregated results at the DAO level, we normalized the time and scaled it from 0 to 1, ensuring comparable results.

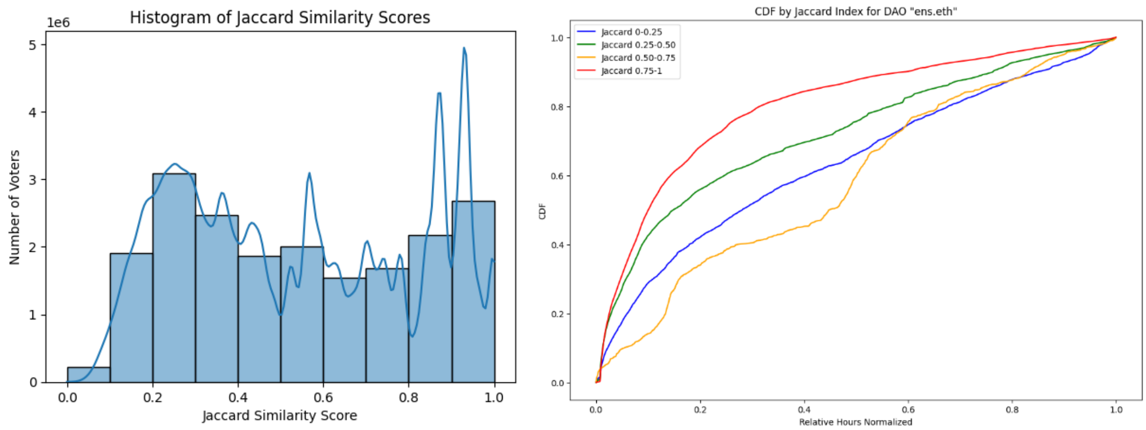

Figure 5-VIII. Distribution of Jaccard index and CDFs for largest DAOs based on Jaccard coefficients

Figure 5-VIII demonstrates that highly connected voters tend to react much faster to the voting process than weakly connected voters. This phenomenon was explored on a large scale by categorizing 1,397 DAOs by size. We computed the CDF for labels *low* and *high* for each

proposal, then employed relative time to aggregate at the DAO level, allowing us to infer the average time when specific thresholds were met.

DAO Size	**Nr. of DAOs**	**10% threshold ***	**20% threshold ***	**40% threshold ***	**60% threshold**	**80% threshold ***
1-50	268	170 (63.4%)	158 (59.0%)	160 (59.7%)	151 (56.3%)	132 (49.3%)
51-100	235	150 (63.8%)	152 (64.7%)	132 (56.2%	125 (53.2%)	111 (47.2%)
101-150	168	111 (66.1%)	112 (66.7%)	94 (56.0%)	86 (51.2%)	85 (50.6%)
151-1,000	527	334 (63.4%)	332 (63.0%)	303 (57.5%)	296 (56.2%)	275 (52.2%)
1,001-10,000	165	85 (51.5%)	93 (56.4%)	95 (57.6%)	96 (58.2%)	94 (57.0%)
10,001-100,000	29	9 (31.0%)	12 (41.4%)	11 (37.9%)	12 (41.4%)	12 (41.4%)
100,001+	5	0 (0.0%)	0 (0.0%)	0 (0.0%)	0 (0.0%)	1 (20.0%)
Total	1397	859 (61.4%)	859 (61.4%)	795 (56.9%)	766 (54.8%)	710 (50.8%)
Median time diff between highly and weakly connected subset of DAO achieving thresholds		14.51%	25.52%	12.28%	4.61%	0.35%
* % of DAOs with highly connected voters achieving the threshold faster than weakly connected						

Table 5-I. Number of DAOs where the normalized time for reaching thresholds (40%, 60%, 80%) for highly connected voters is lower than for weakly connected voters

We examined for each bucket the percentage of DAOs where highly connected voters require less time to reach the specific thresholds than weakly connected voters. Table 5-I. Number of DAOs where the normalized time for reaching thresholds (40%, 60%, 80%) for highly connected voters is lower than for weakly connected voters shows that for smaller or medium DAOs, the share of DAOs with highly connected voters voting faster than weakly connected voters is slightly higher than for larger DAO. This hints that the effect is more important for smaller sized DAOs. Also, there is an estimation of the median difference in time required for reaching the specific thresholds: it subsides as time evolves meaning that the effect of connectivity is more pronounced at the beginning of the voting rather than at the end. The relationship is very weakly negative for lower thresholds and is negligible at the higher thresholds.

Statistical Test	1% threshold	5% threshold	10% threshold	20% threshold	40% threshold	60% threshold	80% threshold
Spearman	-0.197	-0.149	-0.117	-0.072	-0.007	0.014	0.056
Pearson	-0.083	-0.073	-0.065	-0.027	0.019	0.026	0.065
Kendall	-0.163	-0.115	-0.088	-0.054	-0.004	0.010	0.041

Table 5-II. Statistical tests showing the correlation between Jaccard index and the average normalized time of reaching a certain threshold

Our data shows that highly connected voters vote marginally faster than weakly connected voters. The effect has the most considerable magnitude initially and subsides over time. To achieve the 10% threshold, DAOs with highly connected voters need 14.51% less time in comparison to DAOs with weakly connected voters. When reaching the 40% threshold, highly connected voters need 12.28% less time; for the 80% threshold, they require 0.35% less time. However, since the statistical tests range from -0.197 to 0.065, with a p-value of less than 0.001, we deem the results to not be statistically significant.

Additionally, we performed the Kolmogorov-Smirnov (K-S) test (Massey, 1951) to compare distributions across different Jaccard bins. The results show high p-values (ranging from 0.5361 to 0.9985) for all bins, indicating a strong similarity between the distributions. Since p-values above 0.05 typically suggest that the null hypothesis, in this case, that the distributions are the same, cannot be rejected (Dowdy et al., 2004), these findings imply that the distributions across the Jaccard bins are very similar.

5.4 Conclusion and Outlook

While there have been empirical studies on DAOs in recent years, no work has yet connected DAOs to online communities. Our research bridges theoretical and empirical evidence, establishing DAOs as a new type of online community.

We gathered data on 31,002 DAOs, 220,960 proposals, 51,987,413 votes, 154,087,070 token ownerships, and 46,695 historical token prices. Utilizing this extensive dataset, we conducted a 90-9-1 analysis, previously confirmed for online communities. We proceeded with a deciding voter analysis to highlight the unequal distribution of voting power in DAOs. The exploration culminated in two network analyses, revealing that DAOs exhibit properties of scale-free networks and that information diffusion is not affected by the connectedness of voters.

Our contribution to theory and practice begins by aligning DAO properties with the working definitions of online communities from Preece (2000), providing a fresh perspective on understanding DAOs. We then present empirical evidence, demonstrating that analyses traditionally applied to online communities also apply to DAOs in four distinct areas. First, we successfully apply the 90-9-1 rule to DAOs, extending its applicability from online communities. Second, through the deciding voter analysis, we reveal that even within the exemplary 5.33% of active users in a DAO, voting power is unevenly distributed, concentrating at the top, where 20% of all votes decide 60% of all proposals. Third, we establish that DAOs exhibit properties of scale-free networks, a concept widely studied in other domains but not conclusively applied to DAOs. Last, we explore information diffusion within DAOs, assessing the impact of connectivity on the rate of information spread. Our findings indicate that more connected nodes disseminate information at the same rate as weakly connected nodes, contributing to the theoretical understanding of communication within decentralized governance structures.

While we made a considerable effort to compile a comprehensive dataset, our evaluation of DAOs was limited to those utilizing an ERC20 Token strategy for creating network graphs and analyzing the 90-9-1 rule, as both require token holder data. Unfortunately, accurate historical data for other voting strategies such as whitelist voting, ERC721, and ERC1155 was unavailable. Moreover, in creating network graphs that include pricing data, our analysis was confined to tokens listed on Coingecko or similar platforms; for those not listed, we could not reliably confirm the actual value of a token. Reasons for this limitation include scenarios where a token has never been listed, is soulbound (non-transferable), falls under ERC721 and ERC1155 (NFTs), or has a daily trading volume below $100, resulting in extreme price fluctuations. Despite these constraints, as our initial dataset includes all DAOs available on Snapshot and is not a sample, we assert that our results remain rigorous.

Our study establishes a foundation for advanced network analysis within the DAO domain. We anticipate that network analysis holds significant potential to unveil the factors contributing to the success or failure of various DAOs. Given the rapid evolution of DAOs, each possessing unique properties, the field promises exciting avenues for future analysis.

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6 Essay V: Navigating the Research Landscape of Decentralized Autonomous Organizations: A Research Note and Agenda

Abstract

This note and agenda serve as a cause for thought for scholars interested in researching Decentralized Autonomous Organizations (DAOs), addressing both the opportunities and challenges posed by this phenomenon. It covers key aspects of data retrieval, data selection criteria, issues in data reliability and validity such as governance token pricing complexities, discrepancy in treasuries, Mainnet and Testnet data, understanding the variety of DAO types and proposal categories, airdrops affecting governance, and the Sybil problem. The agenda aims to equip scholars with the essential knowledge required to conduct nuanced and rigorous academic studies on DAOs by illuminating these various aspects and proposing directions for future research.

Keywords: Decentralized Autonomous Organizations; DAOs; Blockchain-based Systems; Data Analysis; Governance

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6.1 The Evolution of DAO Research

Decentralized Autonomous Organizations (DAOs) have emerged from blockchain-based infrastructure. In recent years, these new "online communities" have gained the focus of researchers trying to understand the complexities behind them. DAOs have rapidly evolved and display immense diversity today, making it challenging for scientists to define and analyze them. For example, there are DAOs that support critical infrastructure (MakerDAO is responsible for maintaining a complex, algorithmic system to dynamically adjust the token price of DAI, one of crypto's most important digital assets) and DAOs that mostly just party (e.g., ApeCoin DAO is responsible for maintaining the Bored Ape Club's NFTs and their "in real life" events).

However, the definitions of DAOs have also evolved with them. In 2013, Buterin (2013) introduced the idea that companies could evolve into decentralized autonomous corporations (DACs). The next year, he further elaborated on this idea, describing DAOs as entities that live on the internet and exist autonomously (Buterin, 2014). Soon after, Wright and Filippi (2015) described DAOs as software-based entities that can own and trade resources while mimicking traditional corporate governance. By this point, a few real DAOs were beginning to emerge (e.g., Dash), but famously it was not until the 2016 launch of "The DAO" (which was immediately attacked and exploited), when scholars began to pay attention to the risks and potentials of DAOs. By 2017, DAOs began to be recognized for their potential to operate autonomously, emphasizing decentralized decision-making (Dhillon et al., 2017). One year later, the definitions shifted to practical implications, emphasizing real-world business operations and service offerings (Beck et al., 2018; Hsieh et al., 2018). For instance, S. Wang et al. (2019) emphasize the lack of any central authority or management hierarchy for DAOs, however, such claims have never been truly fulfilled and most DAOs remain highly centralized and hierarchical. By 2020, DAOs were recognized for having a community that organizes itself on decentralized infrastructure (El Faqir et al., 2020). Still evolving, in 2021, some researchers shifted their focus to the ways that DAOs have become complex systems that mediate interactions between humans and blockchains and are striving to become entirely autonomous systems with storage and transaction of value, voting functions, autonomous execution of code, and decentralized security infrastructure (Hassan & Filippi, 2021; Rikken et al., 2021; Schillig, 2021).

At the core of every DAO, there are Treasury, Governance, and Community components (Ziegler & Welpe, 2022). In the Treasury, common funds are stored as digital assets, or 'tokens.' For Governance, proposals for change are created and voted on by the community, which must safeguard the treasury's funds, simultaneously protecting against asset exploitation while investing in its future. Communities are networked assemblages of people that typically have low barriers to entry (token ownership is often sufficient to participate). As governance proposals are the data traces that lie between the treasury and the governing community, we focus on them here.

While scholars have many tools to investigate new phenomena like DAOs, robust research requires a deep theoretical understanding and careful data analysis. We aim to highlight common and uncommon pitfalls researchers should be aware of while conducting quantitative analyses on DAOs and detail current research gaps and emerging research agendas. Existing methodologies are discussed and new experimental ones suitable for research on DAOs are proposed.

In the next section, we present recent work on DAOs, highlighting their focal points, methods, empirical findings and shortcomings.

6.2 Recent Research on DAOs

The first discussion of a practical DAO starts with the whitepaper of Jentzsch (2016) and presents implementation details for “The DAO.” Following its brief existence, scholars investigated nascent aspects of DAOs, specifically examining community decision making and proposing preventive measures for future mishaps, as DuPont (2017) and Andryukhin (2018) discussed. Meanwhile, studies by Kondova and Barba (2019), S. Wang et al. (2019), Kaal (2021), Chao et al. (2022), and Qin et al. (2023) delve into the functionalities of DAOs or compare them with existing organizational structures and explore their capabilities. Baninemeh et al. (2023) outline the design principles of DAOs, while Faqir-Rhazoui et al. (2021) and El Faqir et al. (2020) investigate the platforms on which these DAOs operate, alongside analyzing the distribution of their traffic. From a governance perspective, Marko and Kostal (2022) contemplate avenues for its enhancement within DAOs. Sharma et al. (2023) offer analytics of DAOs, explicitly focusing on governance aspects and discussions, while Chohan (2017) and Han et al. (2023) focus on governance issues. Zhao et al. (2022) found that strategic decisions positively impact platform operational performance under some circumstances in DAOs. Ziegler and Zehra (2023) studied practitioners’ rankings of DAOs. Finally, the work of Ziegler and Welpe (2022) differentiates between various DAO types, extending the taxonomy work of Wright (2021).

Currently, research on DAOs is mainly qualitative or based on literature reviews (Andryukhin, 2018; Baninemeh et al., 2023; Chao et al., 2022; DuPont, 2017; Kaal, 2021; Kondova & Barba, 2019; Marko & Kostal, 2022; Qin et al., 2023; Sharma et al., 2023; S. Wang et al., 2019; Ziegler & Zehra, 2023) while only some studies are quantitative (El Faqir et al., 2020; Faqir-Rhazoui et al., 2021; Feichtinger et al., 2023; Fritsch et al., 2022; J. R. Jensen et al., 2021; Liu, 2023; Ziegler & Welpe, 2022).

Due to the sheer variety of DAOs (Ziegler & Welpe, 2022), qualitative studies and literature reviews should be looked at with skepticism when they make claims about DAOs as a whole, instead of as a diverse assemblage of self-constituting commons which sometimes have shared values, goals, and infrastructures. For instance, while the centrality of MakerDAO is clearly evident by the attention it receives in scholarly literature, it is far from representative of the diversity of DAOs. Moreover, most quantitative studies have significant flaws, such as low sample size (Ziegler & Welpe, 2022) and the measurement of early network effects and other sociologically unstable phenomena (El Faqir et al., 2020; Faqir-Rhazoui et al., 2021). The study of Zhao et al. (2022), for example, only targeted MakerDAO[15] and used one year of data in an effort to capture a highly dynamic and evolving community. Other, more recent quantitative studies on voting in DAOs use only a tiny fraction of available data. For example, Feichtinger et al. (2023) investigated the voting of 621 proposals in 21 on-chain DAOs; in 17 of these, they found that 10 participants have the majority of the voting power. Fritsch et al. (2022) investigated only 3 DAOs and 94 proposals. While this empirical research offers valuable insights to nascent phenomena, we must guard against drawing false conclusions, such as when a DAO can or should be considered autonomous or decentralized.

More broadly, scholars have also designed research agendas specifically for DAOs and proposed research into socio-material practices, interactions, human-machine agency, and institutional change (Santana & Albareda, 2022). For instance, Beck et al. (2018) propose a research agenda for governance in the blockchain economy with the dimensions of decision rights, accountability, and incentives.

[15] https://makerdao.com/en/

6.3 Our Contribution

To contextualize the challenges and opportunities facing DAOs, we conduct an integrated literature review. This is a method "that reviews, critiques, and synthesizes representative literature on a topic in an integrated way such that new frameworks and perspectives on the topic are generated." (Torraco, 2005). We perform a two-step approach; first, we gather and critically analyze existing work on DAOs and extract definitions, methodologies, research gaps, and results. During this stage of the review, we gathered 61 articles on DAOs using Google Scholar[16] using the keywords *DAO, Decentralized Autonomous Organization, Blockchain governance, on-chain governance, algorithmic governance, and decentralized governance* and then performed a backward and forward reference search. Recognizing the nascent field and lack of established, high quality scholarly publication venues, we explicitly include pre-prints and in-progress manuscripts from arXiv[17] and SSRN,[18] but we also recognize that our literature search is not exhaustive.

In a second step, we interrogate existing DAO studies by comparing and critiquing data providers, research methods, and the robustness of conclusions. During this step, we experimentally evaluated numerous datasets and perform statistical measurements to assess the practical and theoretical challenges that remain.

6.3.1 Methodological Framework and Meta-Analysis

In this section, we discuss our integrated literature review findings, focusing initially on the challenges of quantitative DAO analysis. We then delve into specific methods for handling

[16] https://scholar.google.com/
[17] https://arxiv.org/
[18] https://www.ssrn.com/

DAO data, including data retrieval, selection, and data problem-solving strategies. Finally, we unveil our map for future research agendas.

6.3.2 Measuring Successful DAOs

There are few published studies that measure, analyze, or predict the performance and success of DAOs other than Zhao et al. (2022), which looked at a dimension of operational performance only. Predicting the performance of organizations has shown to be challenging (Bonaventura et al., 2020; Bose & Pal, 2006; Johnson & Soenen, 2003) and thus we expect it to be very hard to do for DAOs, too. Aside from highlighting research gaps (Santana & Albareda, 2022), scholars have not discussed core questions about this kind of research, especially regarding what ‘good’ performance for DAOs means. We recognize that while investment-focused DAOs may follow the goal of maximizing their returns (typically measured by token price), On-Chain Product and Service DAOs might also try to maximize their token price, Off-Chain Product and Service DAOs might prioritize growth and user retention, and Community DAOs focus on increasing social capital by onboarding, connecting, and educating as many members as possible (Ziegler & Welpe, 2022). Thus, the proximate goal of each DAO remains unclear; given the fluidity of control and rapid development, the performance and success metrics differ from DAO to DAO and cannot be uniformly applied across the landscape. In turn, empirical limits on the available datasets frustrate statistically significant analyses.

Echoing the concerns of DAO community members, most DAO researchers have focused on the key issue of decentralization. Decentralization is important for DAOs because blockchain infrastructures require the effective decentralization of block-processing to avoid security issues, like 51% attacks. However, researchers have failed to explain how these security concerns are manifested in community concerns, resulting in a scholarly echo-chamber that attempts to measure decentralization without an appropriate grounding in organizational theory. Indeed, many scholars have performed roughly the same measurement under different names:

- Braun et al. (2021) use the Herfindahl-Hirschman Index (HHI) $HHI=\sum_{i=1}^{N}s_i^2$
- Sharma et al. (2023) and Sun et al. (2023) measure Gini coefficients $G=\sum_{i=1}N\sum_{j=1}^{N}|s_i-s_j| / 2N^2\mu$
- Liu (2023) study *n*-top players $\sum_{i=1}^{n}s_i$
- Goldberg and Schär (2023) conduct a ‘whale’ (*n*=1 top player) analysis.

These are formally similar measurements that reveal differential relationships. Specifically, HHI and the Gini coefficient both mathematically encapsulate the entire distribution of market shares (with HHI emphasizing the squared influence of each firm’s size and Gini focusing on relative differences), the *n*-top player (and whale) analysis straightforwardly sums the largest shares, offering a more direct, though less nuanced, view of market concentration. We performed similar analyses on our dataset for comparison (see Figures 1, 2, and 3).

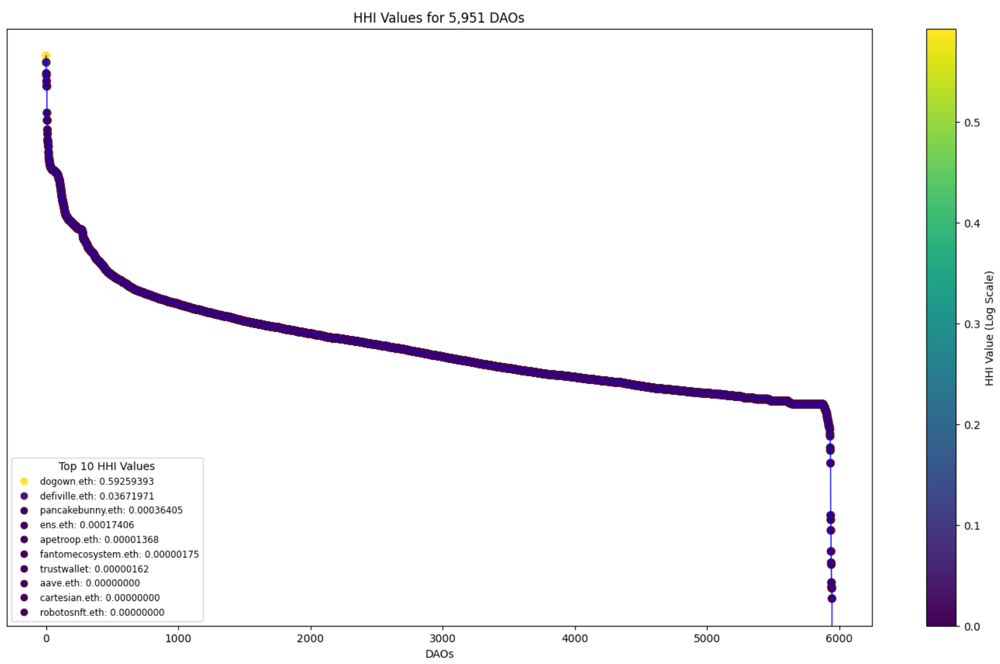

Figure 6-I. Herfindahl-Hirschman Index

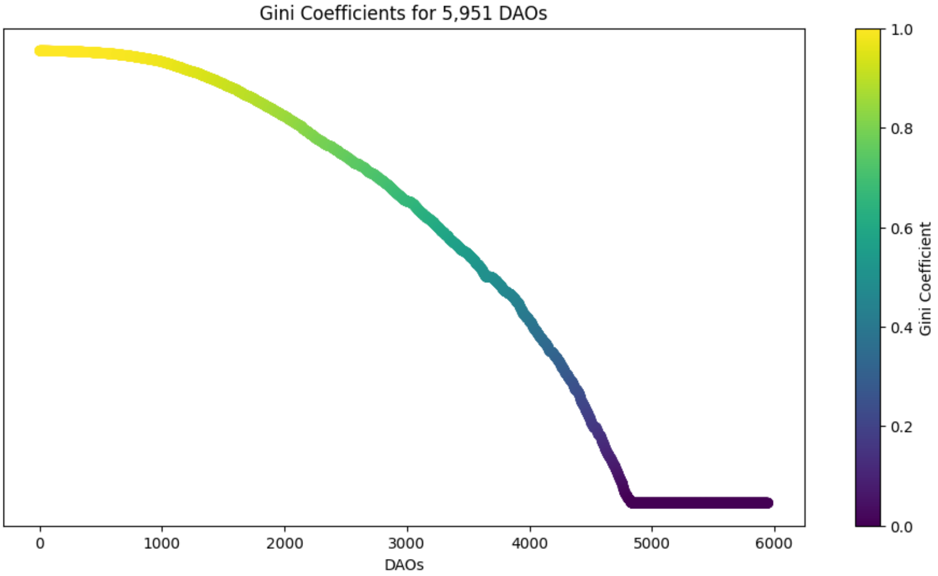

Figure 6-II. Gini Coefficients

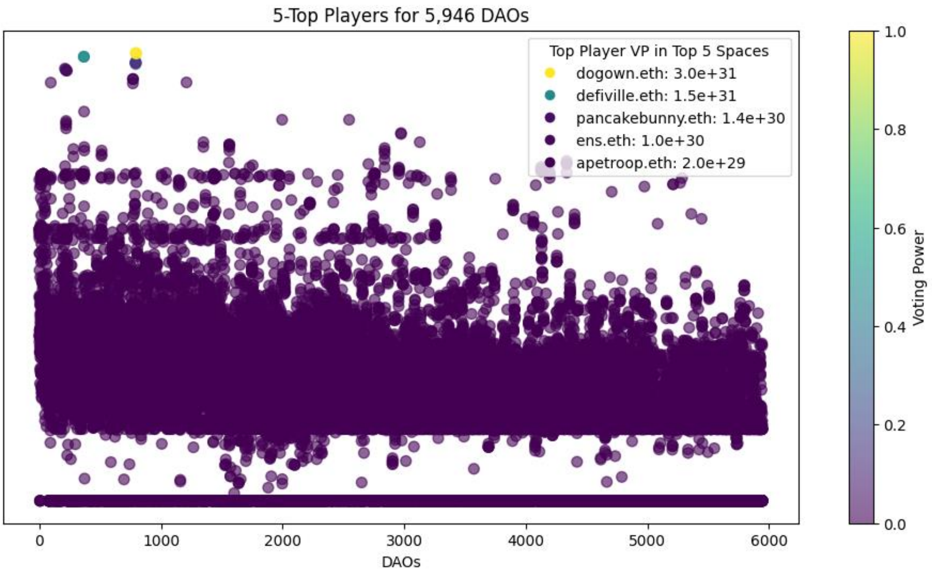

Figure 6-III. n-Player Analysis

Lastly, descriptive statistics on DAOs, such as counts of proposals and votes and comparisons between token prices, may reveal a picture of the current activity of DAOs but they fail to provide a theoretical link to performance, as it has not yet been well demonstrated that many proposals, many voters, or a high token price result in better or worse operational performance for a DAO (the exception in the literature is Rikken et al. (2021), who studied survival rates of DAOs and found that DAOs with more than 20 token holders are more likely to persist).

6.3.3 Working with DAO Data

This section provides a guide for researchers on data collection, selection, and analysis in the context of blockchains and DAOs. It emphasizes the critical distinctions between Mainnet and Testnet blockchains, explores different types of DAOs, and addresses challenges such as token valuation and governance issues. Additionally, the section offers insights into selecting pertinent data, discussing various aspects like the complexities of different DAO models, governance proposal characteristics, levels of community engagement, and the valuation of governance votes in terms of coin voting. The aim is to equip researchers with a foundational understanding of data preparation for effective research in this field.

6.3.3.1 Retrieving Data

Working with quantitative data on DAOs requires proper data cleaning and validation, as with every quantitative analysis. With DAOs, however, there are some less obvious aspects to consider. First, researchers must decide where to get their research data, and a small cottage industry has recently emerged to support these efforts. Prior quantitative research on blockchains was limited by its access to raw blocks (which must be recorded by researchers using custom networking interfaces), lack of standard infrastructure, and the challenges of decoding raw transaction data.

In recent years, several companies have developed tools to simplify these data preparation steps. A prominent source for DAO research is Snapshot,[19] which provides DAO members an integrated interface for DAO voting and offers researchers an API for studying off-chain voting activity by delivering data traces from DAO proposals and votes. DeepDAO[20] provides an analytics engine for researching DAOs, with an estimate of treasury size and voting activity.

[19] https://docs.snapshot.org/tools/api
[20] https://deepdao.io/organizations

Dune[21] takes a different approach to analytics by storing all EVM blockchain data in SQL format; this allows researchers to explore chain transactions through traditional SQL queries or by exploring analytical dashboards designed by other researchers in the community. CovalentHQ[22], Moralis[23], and Flipside[24] have similar APIs to gather relevant data on blockchain events, such as on-chain voting, transfers of cryptocurrencies, and token ownership. Coingecko[25] and Coinmarketcap[26] deliver historical and current price data for most cryptocurrencies. Messari[27] has a diverse set of data about token prices, historical token prices, 24-hour volume, token-economics, research insights, and proposals and votes of DAOs. Lastly, data from on-chain DAOs can be collected from The Graph[28], Boardroom[29] or the DAO Analyzer Dataset (Arroyo et al., 2023) which contains insights on aragon[30], daohaus[31] , and daostack[32].

Without these APIs, researchers must run blockchain nodes to collect data. For example, a researcher can run an Ethereum Node like Geth[33] to directly retrieve Ethereum blockchain data. However, collecting data directly from the Ethereum blockchain has several downsides, such as the complexity of setting up the node, relatively high hardware requirements, and the need to build an indexer or use an existing one such as eth-indexer[34] to retrieve the required data

[21] https://dune.com/browse/dashboards
[22] https://www.covalenthq.com/
[23] https://moralis.io/
[24] https://docs.flipsidecrypto.com/
[25] https://www.coingecko.com/
[26] https://coinmarketcap.com/
[27] https://messari.io/assets
[28] https://thegraph.com/
[29] https://boardroom.io/
[30] https://aragon.org/
[31] https://daohaus.club/
[32] https://daostack.io/
[33] https://geth.ethereum.org/
[34] https://github.com/getamis/eth-indexer

from the blocks. But, despite the challenges, directly accessing block data has the upside of guaranteeing data accuracy, which is not necessarily true for third party data vendors.

Supplemental data and auxiliary graphs support deeper analysis. For instance, governance discussions in advance of formal voting are found across the Internet and in hubs like DAOs Discourse.[35] Also, often DAOs and the blockchains they support are developed using principles inherited from several decades of experience with open source software development. This means projects can be analyzed in terms of software engineering by studying version control, typically Github.[36] These changes to technological infrastructure impact social and community changes and through formal change management processes such as Bitcoin Improvement Protocols (BIPs) and Ethereum Improvement Protocols (EIPs), the community guides the development of the DAO platform. These processes mimic earlier Requests for Comments (RFCs) that established the current paradigm of Internet governance.

6.3.3.2 Mainnet and Testnet Data

We must distinguish between Mainnets and Testnets. Mainnets are public blockchains where actual transactions occur, while Testnets are used primarily by developers to test smart contracts, perform token economic simulations, and to upgrade protocols in production-like environments (Kramer, 2023). Testnet DAOs are unsuitable for research as they mostly contain test data. Most DAOs use the Ethereum blockchain. In the Ethereum Virtual Machine (EVM) Environment, every chain has an assigned ChainID[37] to identify it. Examples of Testnet ChainIDs are 3 (Ropsten), 4 (Rinkeby), 5 (Goerli), 97, 280, 595, 1001, 1002, 941, 42, 43113,

[35] https://www.discourse.org/

[36] https://github.com/

[37] https://chainlist.org/

69, 5553, 65, 9000, 278611351, and 11297108099. For Mainnets, the Ethereum Mainnet has the ChainID 1, and the Polygon Mainnet has the ChainID 137, for example.

6.3.3.3 Types of DAOs

As Ziegler and Welpe (2022) point out, DAOs follow their own highly individual goals. Categorizing DAOs and understanding their goals remains an ongoing research challenge. DAOs are diverse, as we see in the labels used by the analytics platform Messari[38]: Analytics, Art, City, Culture, DAO Tool, DeFi, Developers, Education, Events/Experiences, Future Of Work, Gaming, Incubator, Infrastructure, Metaverse, Music, NFTs, Pay to Earn (P2E), Public Good Funding, Real World Asset Purchase, Research, Science, Sports, Sustainability and Venture. Yet despite the diversity, common goals and attributes can be identified.

Likewise, the structure of DAOs remains enigmatic. Some may act like traditional organizations with hierarchy and formal responsibilities, others like online communities with weak social ties and open-ended goals, and yet others have criminal and anti-social intents. A key challenge facing the structural categorization of DAOs is the lack of empirically informed organizational theory. In recent years, it has been popular to consider DAOs in terms of stakeholder theory (Freeman, 2010; see Morrison, Mazey, and Wingreen 2020), transaction cost economics (Halaburda et al., 2023; Williamson, 1976), and contract design and agency theory (Milgrom and Roberts, 1992; see M. C. Jensen & Meckling, 2019). Others have drawn from more sociological traditions, considering DAOs from the perspective of Hirschman's (1972) *Exit, Voice, and Loyalty* (see also Schneider & Mannan, 2021) and Ostrom's (1990) *Governing the Commons* (see also DuPont, 2023).

[38] https://messari.io/governor/daos

6.3.4 Difficulties Measuring DAOs

This section explores various challenges to understanding the financial dynamics and governance issues in DAOs. From complications in token pricing to plutocracy, the Sybil problem, and the impact of airdrops and spam proposals, this discussion aims to shed light on the complexities researchers face when measuring DAO governance and financial operations.

6.3.4.1 Governance Proposals

Despite early efforts to create fully autonomous systems (Pitt et al., 2020), DAO designers quickly realized that change management requires the effective synthesis of humans and technology. And due to the availability of scarce (valuable) tokens associated with DAOs, coin voting on governance proposals quickly became the norm. Naturally, plutocratic governance also quickly emerged, where those with the largest token holdings control the decisions of the DAO. Diverse efforts to curtail or end plutocratic governance include persistent identity systems (Ethereum Name Service, Proof of Participation, Self-Sovereign Identities, and Decentralized Identities) and mechanisms to address Sybil voting (DuPont, 2023). Nonetheless, on-chain and off-chain coin voting on governance proposals remains the central mechanism of change for DAOs and key to our analysis.

However, governance proposals present numerous challenges to researchers. As with all aspects of DAOs, separating the wheat from the chaff is a persistent issue. Aside from the enduring issue of Sybils and their uncontrolled influence on democratic voting, many governance proposals appear to be tests, jokes, or spam. For instance, in a Snapshot.org dataset up to March 28, 2023, we found 3023 proposals that had “test” in their title. Some proposals seem like jokes, but audacity offers context (famously, Constitution DAO attempted to buy an early manuscript of the US Constitution), so whether a DAO really wants to "buy a lambo,"[39] "buy a Space X Rocket,"[40] or "purchase a Lamborghini Revuelto for Marketing Purposes"[41] is an open question. Many proposals are open to voting for short periods (less than 6 hours), suggesting that they are to be interpreted as noise and filtered from analysis (Figure 6-V, Figure 6-V). On the other hand, Figure 6-VI reveals extremely long running proposals, which are perhaps evidence of governance proposals being used in unintended or unexpected ways.

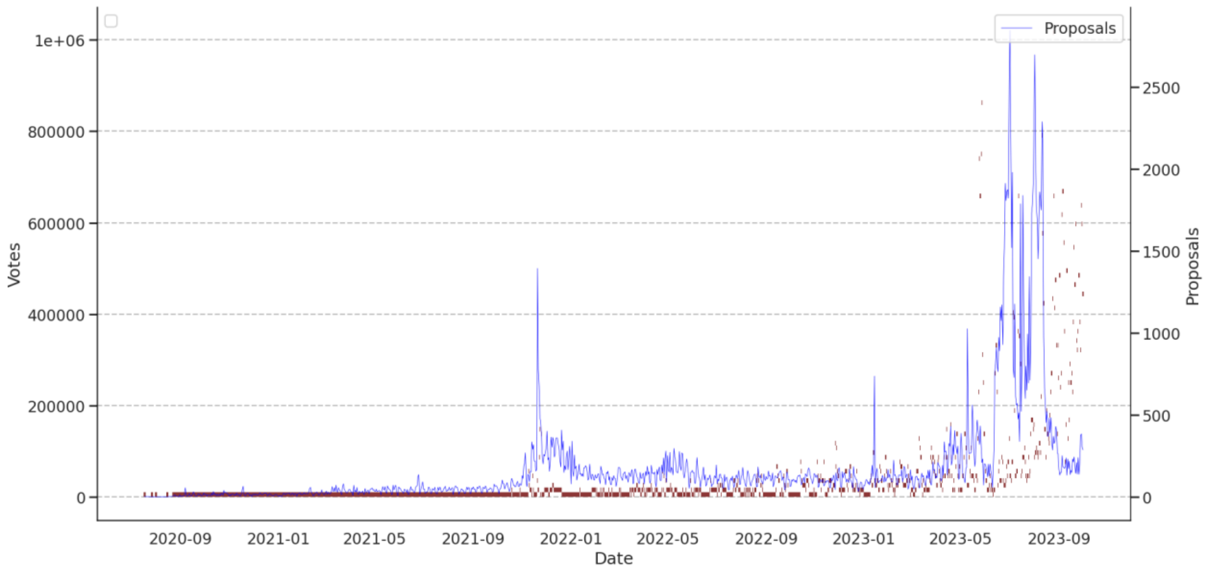

Figure 6-IV. Votes and proposals created over time

[39] https://snapshot.org/#/dumdave.eth/proposal/0x416d2220732166296bb6b36af9a02d86f9e9cd247092ab252ceb6a487cdaca05

[40] https://snapshot.org/#/dumdave.eth/proposal/0x8a247337ad9f9f3d54450755b8fdc676372915e6c485da76d005498fd94303a5

[41] https://snapshot.org/#/1inch.eth/proposal/0xabc97c7a6cfa8c8ef0f8024fc4d3f6bbcb186aa47475867df37119d5b520fda8

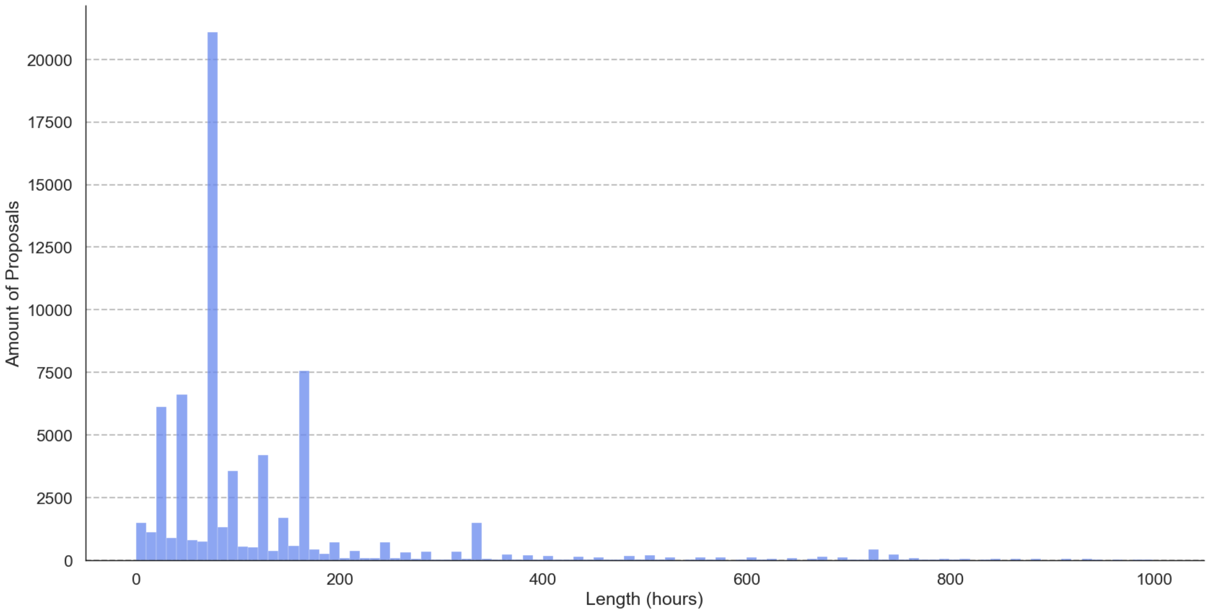

Figure 6-V. Filtered proposal durations (short to medium)

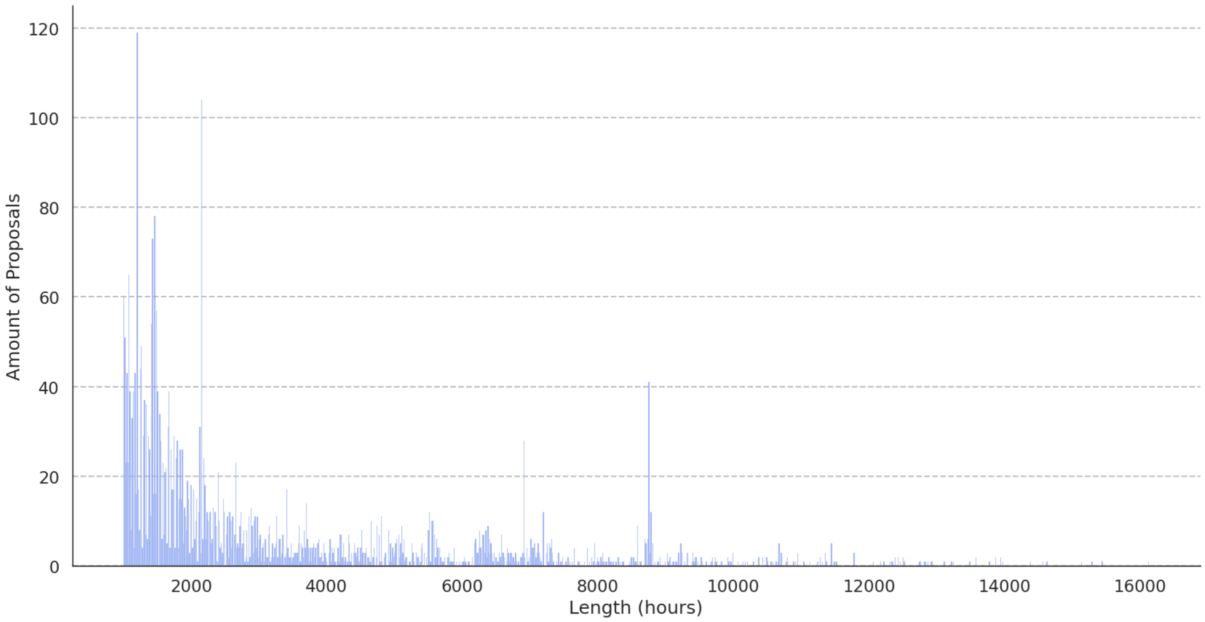

Figure 6-VI. Filtered proposal durations (long)

There are many ways to research governance proposals. Proposal discourse may be statistically measured (*n*-grams), topic clustered (supervised and unsupervised methods), analyzed for sentiment (Natural Language Processing), analyzed for importance (Principal Component Analysis), and so on. A newly popular method to discourse analysis uses Large Language Models (LLMs) like ChatGPT to label and cluster proposals. In a small test with LLMs, experimentally we found new categories for DAOs based on proposal discourse: protocol upgrades/expansions, governance and delegation, partnerships and budgeting, risk parameter adjustments, and treasury rebalancing. LLMs can also answer complex questions, such as "does the proposal affect individual wealth?" which opens up many different opportunities for decision support systems and novel research designs.

6.3.4.2 Community Activity

Determining characteristic and exemplary baseline measurements of online community activity is a fraught activity. Far too often researchers implicitly adopt an econometric approach and evaluate DAOs solely by their token prices. Not only are token prices poorly correlated to measurable activities (token prices tend to change in response to bubble dynamics), they also mask many sociologically important phenomena, such as community commitment, motivations, and interactions with other members. For DAOs, a better metric is voting activity, but voting is complicated by test and junk data, Sybils, and the challenges of identifying and tracking anonymous users.

A DAO's activity must be measured against its scale. Very small DAOs with a handful of members and occasional voting will have a distinct structure in comparison to a large DAO with daily or weekly proposals and thousands of participating members. We expect to see strong ties in small networks and weak ties with many absent or invisible ties across large networks (Granovetter, 1973). Moreover, since DAOs are typically permissive in their membership structure (token ownership is usually sufficient to join), individuals may vote across multiple DAOs and take different roles, such as leadership positions. Often, DAOs financially compensate members for contributions, including leadership, which introduces sustainability questions (see Figure 6-VII). As such, many DAOs restrict who can create governance proposals, allowing only known stakeholders or community leaders to create governance proposals. Complicating matters further, many DAOs (like MakerDAO) utilize delegated voting, so key community members may play an outsize role on account of delegated voting power.

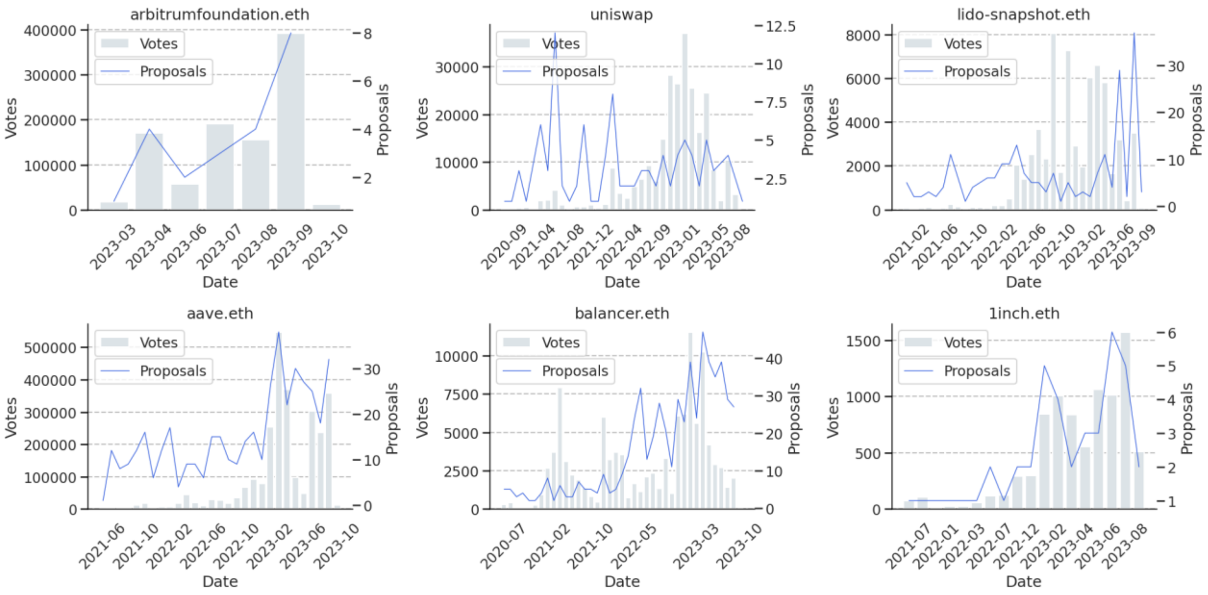

Figure 6-VII. Proposal voting by DAO for major DeFi DAOs

6.3.4.3 Coin Voting

Most DAOs use coin voting. Rather than traditional 'one person, one vote' frameworks, DAOs typically require voters to stake valuable tokens to represent their will. Plutocratic dynamics where large token holders dictate the decisions of the DAO naturally occur, however, the implications of using coin voting in a decentralized environment are not yet well researched. Buterin (2021) highlights issues with decentralized governance (DeGov) in DeFi and offers possible solutions. More broadly, DAOs can be measured and evaluated in terms of treasury size, assets under management (AUM), and total value locked (TVL), although such econometric measurements are necessarily limited, as we discussed above.

6.3.4.4 Token Prices

Not all tokens have monetary value or are tradeable. Non-fungible tokens (NFTs) are singular digital assets that, despite claims about the universal nature of price in neoclassical economics, resist reductionist explanations of their value (see Karpik (2010). Some tokens might even be soulbound, preventing transfers entirely (Weyl et al., 2022). More traditionally, issues with token pricing can be roughly assigned to four classes of error: too little liquidity, untradable or staked tokens, unlisted tokens, and obscure or complex pricing mechanisms.

First, tokens with limited liquidity can experience significant price fluctuations. For tokens with low liquidity, it can be very difficult to discover a price, especially when goods are not homogenous (Milgrom, 2017), which exposes traders to financial risks and introduces analytical complexities. Extreme volatility can render analyses about the effect of token price on proposal outcomes ineffective. More fundamentally, the question of where, how, and why "value" arises is still a conceptual black box.

Second, untradable or staked tokens cannot be used uniformly and users often earmark tokens for specific purposes (Zelizer, 1989). Examples of special purpose tokens include veCRV and sScroll. Unlike traditional monetary instruments, tokens can have mechanisms that decrease or increase each token's voting power (VP) over time, requiring additional data and processing to discover the correct influence of these tokens.

Third, tokens used by new or private DAOs are not yet listed on any central exchange (CEX), such as Coinbase[42] and Binance[43], or any decentralized exchange (DEX), such as Uniswap[44] or SushiSwap[45], making them impossible to price. Fungible tokens may even become non-

[42] https://www.coinbase.com/
[43] https://www.binance.com/en
[44] https://uniswap.org/
[45] https://www.sushi.com/

fungible when engaged in crime; law enforcement in local jurisdictions routinely mark and track illegal transactions and regulatory policies restrict their use.

Fourth, NFTs auctioned on Opensea[46] and similar platforms usually have a floor denominating a minimum price, often corresponding to the price of the last item of the collection sold. However, the next token is not guaranteed to sell for this price, as items are not perfect substitutes. As every NFT is unique, these tokens come with rare attributes that influence the price. Considerable care is required to construct pricing algorithms that are fair and transparent.

6.3.4.5 Token Economics

When conducting financial analyses of DAOs, researchers should examine both on-chain wallets and off-chain bank accounts to accurately assess performance. This dual examination is crucial because DAOs, particularly those operating with both fiat currency and cryptocurrency, can transfer funds between accounts, potentially distorting the financial picture presented by wallet data alone. However, a significant challenge arises in obtaining detailed financial statements from DAOs, including operational costs, income, and salaries. Despite the foundational ethos of transparency and openness in the blockchain and DAO community, the reality is that very few DAOs openly publish their comprehensive business records. This lack of transparency poses a hurdle for researchers seeking to evaluate the true financial health and performance of these organizations.

Additionally, a thorough understanding of token macroeconomic considerations is integral to analyzing DAO finances. This includes examining token burn and mint rates and strategies for token allocations and reserves. To aid in this complex analysis, emerging tools that simulate macroeconomic changes specific to DAOs have become increasingly available. They enable

[46] https://opensea.io/

researchers to model various financial scenarios and evaluate the impacts of different economic strategies. Such advancements in simulation tools mark a significant progression in DAO economic research, offering deeper insights into their financial mechanisms and long-term viability. As we discuss below, this analytical capability is essential for navigating the unique and often intricate economic landscapes of DAOs.

6.3.4.6 The Sybil Problem

The Sybil attack, initially described by Douceur (2002) as "threats from faulty or hostile remote computing elements" on peer-to-peer systems that are "always possible except under extreme and unrealistic assumptions of resource parity and coordination among entities." Due to the anonymity provided by blockchain infrastructure, sybils remain a key problem in real world peer-to-peer system such as Bitcoin and Ethereum. Sybils naturally emerge when new, unique addresses are cryptographically generated from a wallet keychain. Importantly, each new address is cryptographically linked to its generating keychain in ways that only the private key owner can *a priori* determine. And so, transactional privacy is ensured; deanonymizing social networks is infeasible but at its limit deep learning methodologies are chipping away at this anonymity. DuPont (2023) follows recent efforts using deep learning to deanonymize anonymous networks like Bitcoin and Ethereum, using a *k*-anonymity framework (Sweeney, 2002) to identify sybils in DAO governance.

Sybils are particularly problematic for decentralized governance, which relies on coin voting. In a coin voting context, there is no way to ensure democratic processes, which typically require a 'one person, one vote' framework. Instead, due to economic inequality in coin voting, strong plutocratic governance effects emerge. Polycentric governance (DuPont, 2023) offers a flexible community response to sybil attacks, but much more research is necessary to make sybil defense a practical reality for DAO governance.

6.3.4.7 Airdrop Farming and Spam Governance

A unique dimension of Web3 is the presence of so-called Airdrops where specific users are rewarded for early participation, particular actions, or activity in a protocol, blockchain, or decentralized application (dApp) with free tokens that can later be sold for monetary gain or used in governance. Examples of prominent Airdrops are Uniswap, ENS, Bored Ape Yacht Club and Optimism where users have received a non-trivial amounts of tokens (Allen et al., 2023). Out of the twelve notable aidrops that happened between 2014 and 2022, half were retrospective, meaning that the tokens were issued after the project has launched (Allen et al., 2023). Promises of an Airdrop incentivize users to join and participate. For instance, often users must vote on a proposal or otherwise engage with DAO smart contracts to receive a retrospective airdrop. The dispersion of this uncontrolled "free" money often frustrates analysis of DAOs.

6.4 Research Agendas

So far, we have shown how to retrieve, filter, and work with data and identified numerous research gaps, this section offers a perspective on which empirical research questions might be interesting to investigate. Our suggestions are simply a starting point and not exhaustive. We divide the research questions into five themes.

6.4.1 Descriptive Statistics of Online Communities

Descriptive analysis is needed to get an overview of what is currently happening across the DAO landscape. Using time-series data, the evolution of the field over time could be shown. A first glimpse of what this research looks like is provided by Q. Wang et al. (2022), where they descriptively analyze the Snapshot dataset. Since voting occurs in networks, graph analysis also offers many rich opportunities for statistical insight, as (DuPont, 2023) discovered in the Snapshot dataset.

6.4.2 Games, Players, and Institutions

The exploration of games, players, and institutional actors in the context of DAOs, presents a rich area for scholarly inquiry. The impact of prominent venture capital firms like a16z and Paradigm in the DAO landscape is an emerging topic of interest. These firms often have significant token holdings, giving them considerable sway in DAO governance. Their strategies and decision-making processes in this realm are yet to be fully understood by the scientific community. Similarly, the involvement of student clubs such as Penn Blockchain and MIT Blockchain in DAO governance through delegated tokens is a novel development. These groups represent a younger, academically oriented demographic that could have unique motivations and strategies.

Game Theory, as initially proposed by Neumann and Morgenstern (1944), provides a foundational basis for modeling the behavior of these players in DAOs. The application of dynamic games with incomplete information, as conceptualized by Harsanyi (1967), is also particularly relevant. In the context of DAOs, where information asymmetry and changing dynamics are prevalent, these models can help predict and analyze the strategic interactions between different stakeholders.

Moreover, the concept of long-run games, explored by Fudenberg and Levine (2008), is crucial to understanding the sustained interactions and strategies within DAOs. These long-term perspectives can shed light on how continuous participation by known and anonymous entities influences the governance and evolution of DAOs. Their long-term strategies, including investment decisions and voting behaviors, can significantly shape the trajectory of a DAO's development and success.

6.4.3 Models: Correlative and Analytic

In the study of DAOs, the need to develop models is pivotal for advancing our understanding of their dynamics and performance. Correlative models primarily examine statistical relationships between variables. For instance, research leveraging measures such as degree centrality, closeness centrality, eigenvector centrality, and betweenness centrality—concepts foundational to network analysis as discussed in Grassi et al. (2010)—has been instrumental in understanding online communities. However, the application of these measures to DAOs remains underexplored. While these centrality measures are well-established in network theory (see Brede (2012), for an in-depth discussion on network centrality measures), their direct correlation to DAO performance and governance structures is not yet established, leaving a significant gap in the field.

Analytic models, on the other hand, extend beyond identifying correlations to delve into the underlying mechanisms and causal relationships. This approach is crucial in understanding the complexities of DAOs, particularly in aspects like governance and the influence of major stakeholders or 'whales.' While foundational theories in economic governance provide a basis for understanding organizational structures and decision-making processes, their application to the novel context of DAOs remains largely uncharted. The analytic approach could potentially uncover how governance models and the presence of token inequality affect the overall performance and decision-making efficacy within DAOs.

However, both correlative and analytic research in the context of DAOs face a significant challenge due to the absence of a robust theoretical foundation that specifically links these traditional measures and theories to the unique characteristics of DAOs. As a result, there is a pressing need for research that not only applies these established concepts and measures but also adapts and evolves them to suit the distinctive nature of DAOs. This would involve a critical examination of the role of decentralization in performance, the impact of token economics on governance, and the influence of major stakeholders, thereby contributing to a more comprehensive understanding of DAOs in the broader field of blockchain technology and decentralized systems.

6.4.4 Financial Risk and Economic Simulations

Understanding financial risk management in the context of DAO governance is a complex yet crucially understudied topic. Traditional financial risk management tools, both commercial and private, are well-established in the crypto sphere, but their adaptation to DAO governance remains a largely unexplored area. This gap has led companies like Gauntlet to pioneer simulating DAO governance dynamics for risk management. Gauntlet's work focuses on areas such as assessing the impact of adjusting risk parameters in Decentralized Finance (DeFi) DAOs, modelling interactions across different protocols, and optimizing incentive schemes.

Organizations like Token Engineering Commons and Commons Stack have developed tools to support economic and governance simulations. These tools are invaluable to researchers seeking to understand and model the complex dynamics of decentralized governance and their economies.

The Augmented Bonding Curve (ABC), developed in collaboration with Block Science, is a form of a bonding curve smart contract that regulates the relationship between token supply and price. It incorporates novel features such as an allowlist with a "trust score" and a common pool treasury, supported by entry and exit tributes. This design aids in establishing a self-sustaining microeconomy within communities, thereby enhancing economic stability and ensuring liquidity in token ecosystems. Complementing ABC, Conviction Voting and Praise emerge as pivotal tools for governance and community engagement. Conviction Voting offers an alternative for collective decision-making by enabling continuous support for proposals, where the conviction or voting power increases the longer tokens are staked. This mechanism democratizes influence, allowing smaller token holders to counterbalance the sway of larger stakeholders, and tackles challenges like governance attacks and voter apathy. On the other hand, Praise serves as a community intelligence system that effectively acknowledges, quantifies, and rewards often overlooked contributions through a peer-to-peer feedback mechanism. This system fosters community engagement and intrinsic motivation among participants.

Additionally, for researchers interested in system dynamics and scenario analysis, cadCAD stands out as a versatile simulation tool. This open-source Python package facilitates the design, testing, and validation of complex systems, integrating with empirical data science practices. With capabilities like Monte Carlo methods, A/B testing, and parameter sweeping, cadCAD is crucial for conducting "what if" analyses, allowing researchers to explore various outcomes and strategies within DAO ecosystems. Together, these tools offer an emerging suite for researchers.

6.4.5 Theory Development, Theory Confirmation, and Paradigm Shifts

Theories that are applicable in other fields, such as online communities in information systems, might also apply to DAOs, such as the Small World Phenomenon (Kleinberg, 2000; Milgram, 1967), Scale-Free Networks (Barabasi & Albert, 1999; Caldarelli, 2008), Community Resilience (Norris et al., 2008), Preferential attachment (Barabasi & Albert, 1999; Kunegis et al., 2013) or information diffusion (Chongfu, 1997). None of these theories have been applied to DAOs yet.

6.5 Conclusion

This agenda highlights the challenges and complexities involved in quantitatively analyzing DAOs. By outlining the limitations of existing metrics and posing critical questions that have yet to be addressed, we provide guidelines for future scholarly research in the evolving field.

The analysis and measurement of DAOs' present a complicated problem. The concept of performance itself is fragmented across different types of DAOs – ranging from investment-centric to community-focused entities. The issue of decentralization adds another layer of complexity; while it is a defining feature of DAOs, its impact on operational performance is still unclear. Even if correctly applied, existing statistical measures may yield insignificant insights due to the diverse nature of DAOs and the problem of retrieving clean and relevant data. As the field matures, datasets used for the research on DAOs should be publicly shared and further refined by future scientists. Furthermore, as the field matures, previous insights may no longer be applicable, as legacy DAOs may no longer be active or may have changed in unforeseen ways.

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7 Essay VI: Classifying Proposals of Decentralized Autonomous Organizations using Large Language Models

Abstract

Our study demonstrates the effective use of Large Language Models (LLMs) for automating the classification of complex datasets. We specifically target proposals of Decentralized Autonomous Organizations (DAOs), as the classification of this data requires the understanding of context and, therefore, depends on human expertise, leading to high costs associated with the task. The study applies an iterative approach to specify categories and further refine them and the prompt in each iteration, which led to an accuracy rate of 95% in classifying a set of 100 proposals. With this, we demonstrate the potential of LLMs to automate data labeling tasks that depend on textual context effectively.

Keywords: Decentralized Autonomous Organizations, Large Language Models, Proposals, DAOs.

Current status:

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7.1 Introduction

Decentralized Autonomous Organizations (DAOs) are information systems with different functions that either mediate interactions between humans and blockchains or operate as a completely autonomous system with features that enable storage, transaction of value, voting mechanisms, autonomous execution of governance decisions in a decentralized environment (Hassan & Filippi, 2021; Rikken et al., 2023; Schillig, 2022)

Governance in DAOs is implemented with proposals that have different phases such as pre-discussions, forum discussions, voting, and implementation. These proposals can change any aspect of the DAO, such as allocating funds, changing risk parameters of a Decentralized Finance (DeFi) application, upgrading the protocol, changing the rule for governance, or engaging in partnerships with other DAOs or companies.

DAOs can take many different forms that considerably change how governance works. For example, off-chain product and service DAOs do not run any protocol updates, investment-focused DAOs do not change risk parameters, and a networking-focused community DAO will decide on many more partnership proposals than an on-chain product and service DAO (Ziegler & Welpe, 2022).

Prominent DeFi DAOs such as Aaave, Uniswap, Balancer, Safe, Compound, Lido, and Arbitrum have decided on 1645 proposals and discussed those on 3742 topics on the forums from July 2020 to December 2023, which highlights the frequent use of governance proposals to run the DAOs. In the same timeframe, 231442 proposals were created by 35238 DAOs on Snapshot[47] alone.

[47] https://snapshot.org/#/

This vast amount of very different proposals makes it very difficult for researchers to analyze the impact of proposals on, for example, DAO performance since a standard proposal that makes a minor adjustment of a parameter from a DeFi protocol only has a minor effect on the DAO is in large scale indistinguishable from a high impact proposal that makes a change to the core protocol. Currently, researchers have to manually analyze proposals to then use them in a subsequent analysis.

This manual process for classification is very time-consuming and, therefore, very costly on a large scale. At a scale of more than 231442 proposals in Snapshot alone, this task is also unfeasible even for a more extensive research team.

Therefore, we formulate the following research questions:

- **RQ1**: What categories of DAO proposals exist, and what is their prevalence?
- **RQ2**: How can researchers automatically classify DAO proposals?

Contrary to previous and related research that uses data augmentation to enhance training to be more diverse, this approach performs a fully-fledged classification of context-related datasets.

The remainder of this paper is structured as follows. Section 2 introduces our design science methodology with Peffers et al. (2007) and Nickerson et al. (2013). In Section 3, we present our three resulting artifacts. Finally, in Section 4, we conclude.

7.1.1 Method

In this work, we use the Design Science Research Method (DSRM) proposed by Peffers et al. (2007) as a guideline and Nickerson et al. (2013) to create a taxonomy of proposals in DAOs.

Following Peffers et al. (2007), we first identify the problem, state our motivation, and justify the value of a solution. Second, we define the objectives for a solution by inferring the solution's objective from the stated problems. Third, we follow Nickerson et al. (2013) to build a taxonomy of proposals while continuously improving the categories, LLM parameters and the LLM prompt. During each iteration, we perform a demonstration by classifying proposals and an evaluation by comparing the accuracy of the LLM classification against manual classification by delegates.

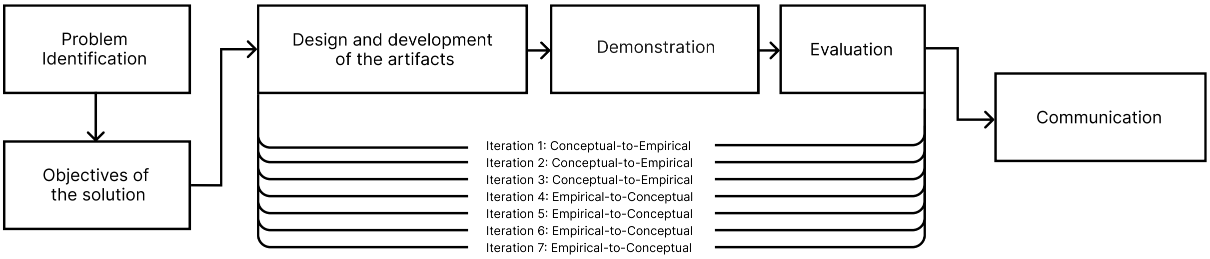

Figure 7-I. Design Science Research Method adapted from Peffers et al. (2007)

The taxonomy development method of Nickerson et al. (2013) consists of seven steps. First, researchers need to determine a meta-characteristic that describes the purpose of the taxonomy. Second, ending conditions must be defined to determine when the iterative approach for building the taxonomy ends. Third, an approach for building the taxonomy needs to be chosen; This is also the return point after each iteration. The researcher has two options: The empirical-to-conceptual approach and the conceptual-to-empirical approach. In the empirical-to-conceptual approach, researchers first identify a new subset of objects, then identify common characteristics and group objects, and lastly, group characteristics into dimensions to create or revise the taxonomy. In the conceptual-to-empirical approach, the researchers first conceptualize new characteristics and dimensions of objects, then examine objects for these characteristics and dimensions, and end by creating or revising the taxonomy. After each iteration, the researcher checks for the before-defined ending conditions. If they are met, the taxonomy is complete. If not, the researchers iterate again by selecting a new approach (Nickerson et al., 2013). We use this methodology in Section 3.3 Design and Development, Demonstration and Evaluation.

7.1.2 Problem definition

There exists no broadly accepted categorization of DAO proposals. As DAO governance is very diverse in its tasks, a joke proposal to "buy a lamborghini" is indistinguishable from a significant proposal that, for example sets a paramters in the governed DeFi protocol without manual review of the proposal by a human. This manual classification is a very time-consuming and, therefore, expensive task but required for further research into the effectiveness of governance in DAOs.

7.1.3 Objectives of the solution

We, therefore, aim to define categories that cover the whole spectrum of proposal types in DAOs that can be used for further, more insightful research on DAO governance. In addition, we require a reliable and highly accurate classification method that utilizes LLMs to automate classification. Lastly, we want the outcome of this research to be highly re-usable for other researchers.

7.1.4 Design and Development, Demonstration and Evaluation

In total, we create three artifacts: Proposal categories, the LLM prompt, and the LLM framework parameters. We start by creating the proposal categories using the iterative taxonomy-building methodology of Nickerson et al. (2013) with the intent of creating proposal categories and not a fully-fledged taxonomy. According to the iterative approach of Nickerson et al. (2013), we first define our meta-characteristics as Categories to differentiate different types of proposals of DAOs usable for automatic classification with an *LLM.*

Next, we define our ending conditions by adopting the subjective ending conditions of Nickerson et al. (2013). We, therefore, require our categories to be concise, robust, comprehensive, extendible, and self-explanatory. In addition to the subjective ending conditions, we also define objective ending conditions that deviate from the objective ending conditions of Nickerson et al. (2013), as we are not building a taxonomy but merely categories. Their ending conditions primarily refer to the splitting, merging, addition, or deletion of dimensions or categories in each iteration, asking researchers to do another iteration when one of the named events happens. We define two ending conditions: *no new category has been created in the current iteration*, and *no modifications have been made to existing categories.* Lastly, we define an ending condition closely related to the other two artifacts, LLM prompt and LLM framework parameters: *At least 90% classification accuracy during the evaluation of the current iteration.*

Following the basic setup, we start performing our iterations. In Table 7-I, we show our seven iterations, complete with the demonstration and evaluation as required by Peffers et al. (2007). We abbreviated conceptual-to-empirical as *c-e* and empirical-to-conceptual as *e-c*. The iterations were performed as follows: We first conceptualized new categories or derived categories from DeFi DAOs for the category artifact. The conceptualization was performed with the help of six delegates of DAOs. Delegates in DAOs receive voting rights from tokenholders and vote in their names. They actively participate in governance and get paid for this activity. Therefore, their insights for categorization were invaluable. The observerations of the empirical-to-conceptual rounds stem from the DAOs aave.eth, arbitrumfoundation.eth, balancer.eth, comp-vote.eth, lido-snapshot.eth, safe.eth, uniswap. More specifically, from their respective Snapshot spaces and discourse forums. The iterations for the LLM prompt and LLM parameters were performed using a literature review about parameters and trial and error for the LLM prompt until the LLM replied with a valid JSON that included a classification of the input proposals. In total, we performed three conceptual-to-empirical and four empirical-to-conceptual iterations.

Iteration	Design and Development	Demonstration	Evaluation
1 c-e	Conceptualization of the Dimensions, initial taxonomy, initial prompt, initial llm parameters	10 Proposals classified	Classification Accuracy 10%
2 c-e	Changes to prompt and LLM parameters to get consistent results; Makes Categories much more verbose, c-e through balancer, uniswap, safe, lido, aave, compound, arbitrum	10 Proposals classified	Classification Accuracy 20%
3 c-e	Changes to LLM prompt for consistent results in JSON format; Classification of 20 Proposals by 6 different delegates under the lead of a researcher; Workshop to improve categories with 6 delegates; Update of Categories	20 Proposals classified	Classification Accuracy 20%
4 e-c	Interview with 5 delegates and 4 DAO operators; Add very specific categories such as gauges, whitelisting wrapped tokens, gas rebates, managing airdrops to their respective categories; Manually classify 100 proposals with delegates and researcher; Update of Categories	100 Proposals classified	Classification Accuracy 62%

5 e-c	Add very specific categories derived from the 100 proposals that were misclassified; Update Categories	100 Proposals classified	Classification Accuracy 84%
6 e-c	Manually Classify 100 Discourse discussions by a researcher and the delegates; Add specific categories derived from the 100 proposals that were misclassified; Update Categories	100 Proposals classified; 100 discourse discussions classified	Classification Accuracy 92% proposals, 77% discussions
7 e-c	Add very specific categories derived from the 100 discourse discussions, and the 100 proposals; No updates to categories	100 Proposals classified; 100 discourse discussions classified	Classification Accuracy 95% proposals, 95% discussions

Table 7-I. Iterations according to Nickerson et al. (2013)

7.1.5 Communication

We shared our research findings through various channels to reach a broad audience. For the scientific community, we compiled this detailed research paper. Additionally, we crafted a blog post featured in the news section of StableLab, a delegate company, making our research accessible to a broader audience. To further enhance the visibility of both the research paper and the blog post, we actively promoted them across several social media platforms.

7.2 Resulting Artifact

In this chapter, we present the three resulting artifacts, starting with the categorization of DAO proposals, then showing and explaining the LLM prompt, and lastly, we present the LLM parameters and explain them. The focus of this chapter is that other researchers can directly extract the three artifacts from this research paper and classify their existing dataset on DAO proposals using our approach, therefore improving the specificity of their research.

7.2.1 Categorization of DAO Proposals

Treasury and Asset Management (TAM)

Oversee the DAO's own treasury and assets. This encompasses decisions concerning the security, investment, diversification, and financial reporting of the DAO’s own assets, as well as managing associated risks. In this context, the DAO is the asset owner, and these assets form part of its treasury. This also includes potential airdrops that the DAO could receive.

Protocol Risk Management (PRM)

Manage operational, technical, liquidity, and other risks related to the protocol or the assets held within the protocol. It also includes Risk and Parameter Reports and Updates related to managing the protocol risk. Responsibilities include adjusting protocol parameters (also referred to as risk parameters), enlisting or delisting assets, ensuring the safety of value and assets locked in the protocol, identifying potential attack vectors, addressing risks inherent to protocol operations, rectifying technical vulnerabilities, and navigating specific ecosystem or contextual threats (which encompasses regulatory and legal risk management).

Protocol Features and Utility (PFU)

Enhance and oversee the protocol's functionalities and utility. Responsibilities encompass developing and deploying new code, implementing protocol upgrades, launching new products, deploying new gauges, implementing liquidity mining programs, implementing protocol incentives, expanding the core protocol to additional chains and Layer 2 solutions, and managing the utility of the protocol's native token(s).

Governance Administration and Framework Management (GAFM)

Covers proposals that direct the governance process by refining and standardizing the governance framework, rules, processes, templates, and timelines. It also includes Governance Reports and Updates regarding to Governance. Responsibilities encompass defining roles, managing voting mechanisms and parameters, setting eligibility criteria for voting power, whitelisting tokens into voting escrows and governance contracts, managing Snapshot space and configurations, and determining quorum thresholds. Additionally, this vertical addresses proposals that create or iterate upon processes for onboarding and offboarding roles and entities vital to governance operations, such as service providers, facilitators, working groups, and councils.

Budget Allocation and Work Management (BAWM)

Covers proposals that allocate the DAO's budget to internal DAO projects, tasks, and roles requiring execution or oversight. These initiatives may be singular projects or ongoing operations. It includes Community Updates from service providers that keep the DAO informed on various activities, excluding Governance Reports, Financial Reports, and Risk and Parameter Reports. It identifies service providers, individuals, or teams who take on these responsibilities and carry them out according to the defined Scope of Work and designated deliverables. This ensures the efficient utilization of resources in alignment with the DAO's strategic goals and operational demands. This encompasses the allocation and management of duties and work related to marketing, operations, software development, and risk and financial management.

Partnerships and Ecosystem Development (PED)

Encompasses proposals aimed at driving external growth via strategic partnerships and multifaceted strategies. The focus is on bolstering the DAO/protocol ecosystem through the formation and maintenance of partnerships, launching educational campaigns, overseeing grant programs, engaging in regulatory and legal activism, contributing resources to external foundations that contribute to wider ecosystem development, and allocating budgets to external software development projects that build upon the core systems of the protocol. Additionally, it emphasizes initiatives designed to keep or/and draw more participants into the protocol ecosystem, such as making airdrops and making users whole in front of eventualities. Also Includes activities that foster community spirit and engagement, such as meetups, social media interactions, content creation, and other forms of outreach that do not explicitly fall under marketing or partnerships. Also covers Informative materials and discussions aimed at improving the knowledge base of the DAO's community members regarding blockchain, the protocol's features, and best practices within the space. Furthermore, includes recognizing and managing the contributions that do not directly impact governance but contribute to the health and growth of the DAO’s ecosystem, such as voluntary community moderation, unsolicited user-generated content, and miscellaneous feedback.

Miscellaneous (MISC)

Comprehensive umbrella for activities, requests, and contributions that fall outside the predefined governance verticals or are tangential to governance yet are contribute to the DAO's operations. It includes support requests for technical assistance and user troubleshooting, addresses general inquiries about the DAO and its operations, and translation of important documentation to other languages.

Statistical analysis of proposal category distribution

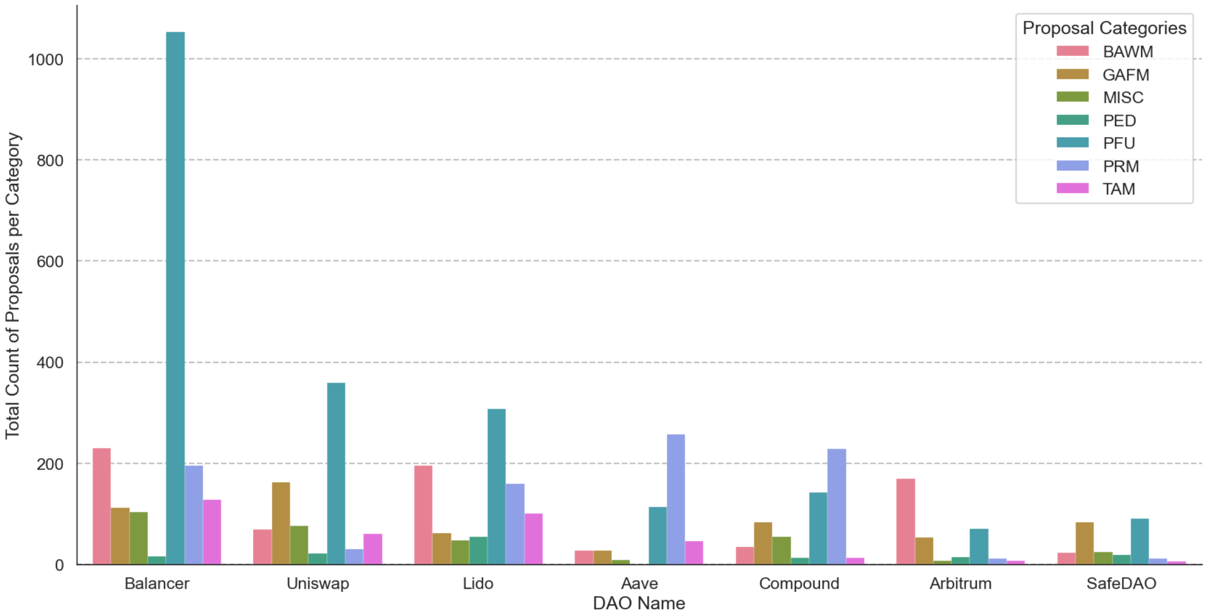

Figure 7-II. Proposal category occurrence by DAO in total numbers

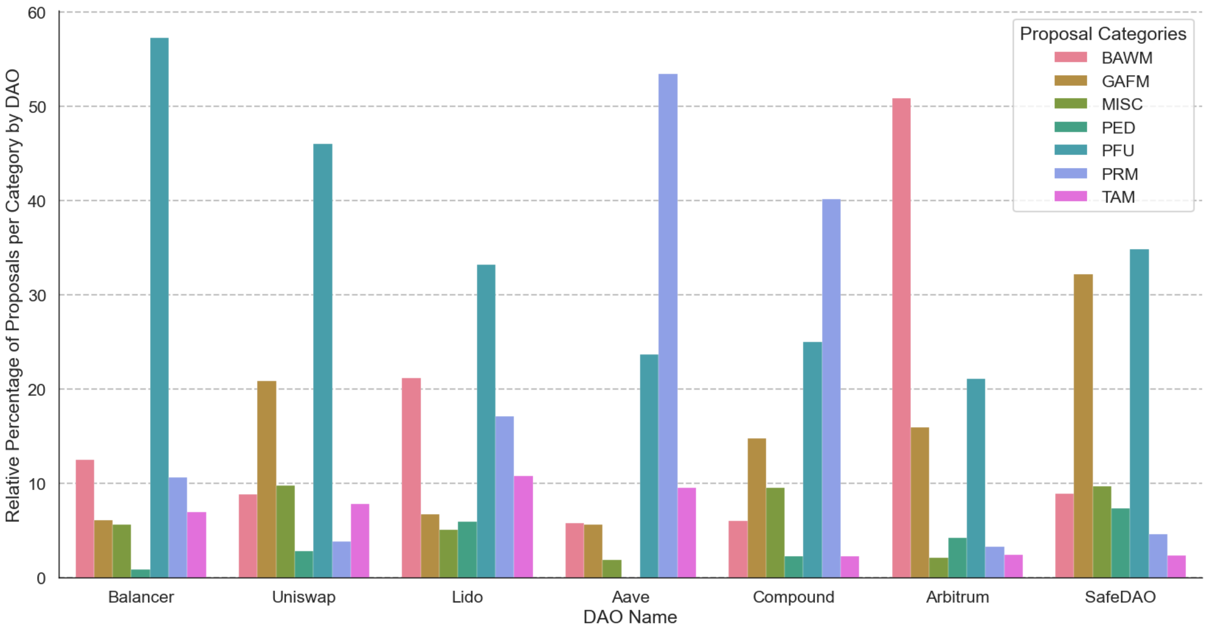

Figure 7-III. Proposal category occurrence in relative percentages by DAO

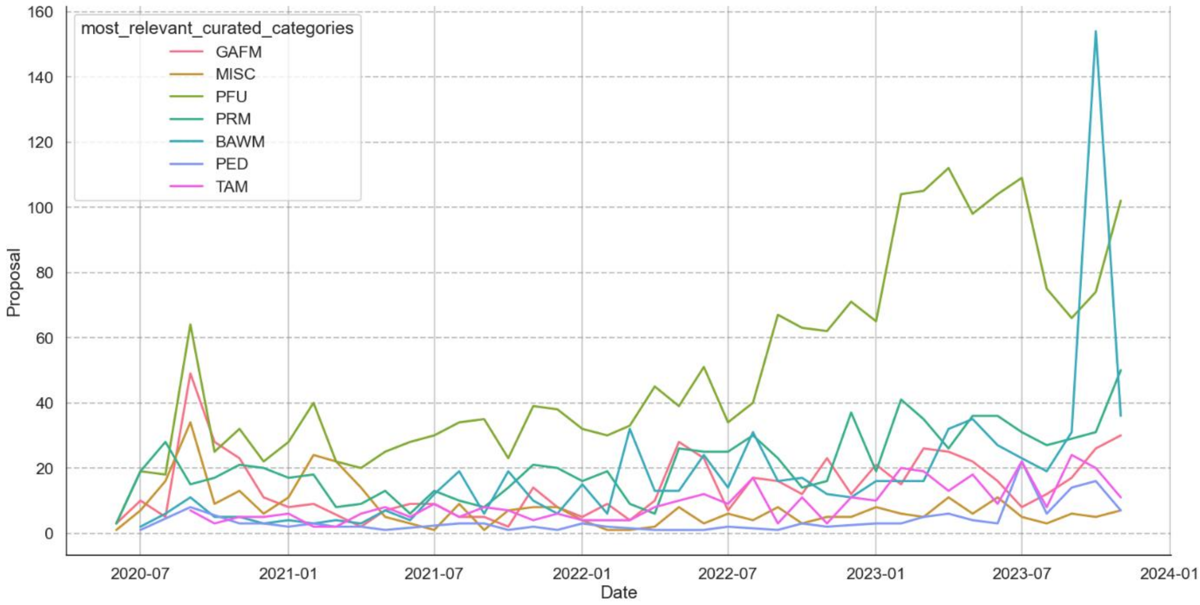

Figure 7-IV. Proposal count in the selected DAOs over time

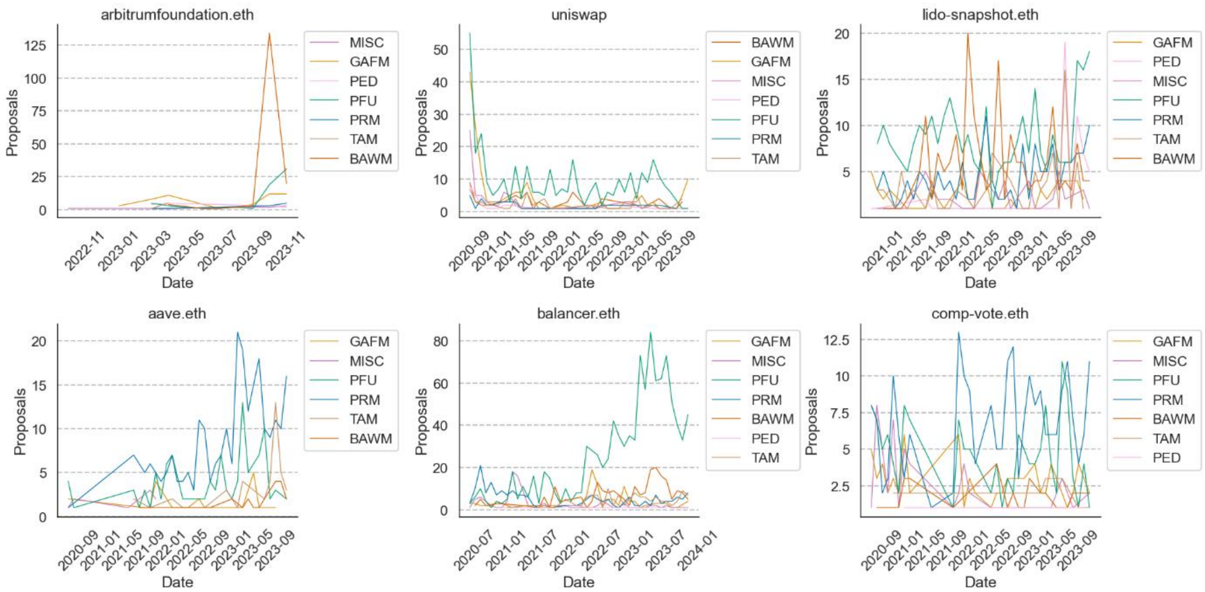

Figure 7-V. Proposal count by DAO and category over time

For all figures, only the most predominant proposal category was counted. When, for example, a proposal has a rating of 0.9 for GAFM and 0.8 for BAWM, it will only show up as GAFM in the charts. From Figure 7-V we can see that both lending protocols aave.eth and comp-vote.eth primarily have PRM proposals, while the exchanges uniswap and balancer.eth have mostly PFU proposals and balancer.eth has more proposals in total because of the many gauges.

7.2.2 The Prompt

During the creation of the prompt, we needed to fulfill several requirements. First, categories needed to be explained in the prompt, and their abbreviation must be directly stated as they are required for the output. Second, the full text of the proposal body and the title must be included in the prompt in a way that the body or title of the proposal can not be mistaken as part of the instructions. Third, clear instructions are needed on what data the LLM should compute. Fourth, our goal was to extract as much information as possible from the proposal using a single prompt, as the additional computational power required to compute more data points from a proposal within one prompt is minimal compared to re-running all proposals again. Fifth, we require the LLM to provide a clear reasoning as to which category was chosen for a proposal. We do this to be able to iterate on wrongly classified proposals. Six, we require the output to be in a valid JSON format so that we can directly store the output in a relational database and further use it from there.

In addition to the categorization, we prompted the LLM to check if the personal wealth of the voter is affected, come up with its own categorization, provide the perceived risk for the dao of this proposal, extract the total cost and revenue, perform emotion detection and sentiment analysis, rate the professional structure of the proposal and check if the given proposals is a linked to a previous proposal and if it is a recurring proposal.

7.2.3 LLM Model (Parameters)

For the parameter selection, we are limited to those available in the API reference of OpenAI as we use GPT-4 for this study. Four of the parameters are OpenAI specific, while three are generally available in most LLMs. We first start with the particular OpenAI parameters:

- **model**: specifies the AI model to be used for generating responses. In this case, "gpt-4-0613" indicates a specific version of the GPT-4 model.
- **messages**: This is an array of message objects representing the conversation history. Each message is a dictionary with two keys:
- **role**: Can be either "user" or "assistant," indicating who is sending the message.
- **content**: The actual text of the message. In this case, the prompt would be the variable containing the user's input.
- **max_tokens**: This determines the maximum length of the response. The value 500 indicates that the response can be up to 500 tokens long. A token can be a word or part of a word, so this doesn't directly translate to a specific number of words.

The following three parameters change the outcome of the prompt by introducing randomness, penalizing repetition, or the likelihood that new topics are introduced:

- **temperature**: This controls the randomness of the response. A temperature of 0 means there is no randomness; the model will always give the most likely response based on its training. Higher temperatures lead to more varied and sometimes less predictable responses (OpenAI, 2023; Xue et al., 2023). We set this to 0.
- **frequency_penalty**: This reduces the model's tendency to repeat the same line of text. A penalty of 0 means there's no adjustment for repetition. We set this to 0.
- **presence_penalty**: This influences the model's tendency to introduce new topics or concepts. A penalty of 0 means the model isn't encouraged or discouraged from introducing new topics. We set this to 0.

7.3 Conclusion

Our study aims to improve DAO research to understand their features better and open up more ways of evaluating them. We set the goal of finding categories for DAO proposals, finding their prevalence, and automatically classifying them. Our primary motivations for these goals are the diverse proposals that govern DAOs that can not be universally used for research and the inaccessibility of manually classifying large quantities of data.

To reach this goal, we have performed a design science research method according to Peffers et al. (2007) with seven iterations in the steps of design and development, demonstration, and evaluation. Within these iterations, we performed three conceptual-to-empirical rounds and four empirical-to-conceptual rounds. We draw from the experience of delegates who have voted on hundreds of proposals and evaluate the outcome of each demonstration by comparing the results of the LLM to our manual classification. In our last iteration, we reach an accuracy of 95% over 200 data points.

With this method, we successfully created three artifacts. First, the categories for proposals: Treasury and Asset Management, Protocol Risk Management, Protocol Features and Utility, Governance Administration and Framework Management, Budget Allocation and Work Management, Partnerships and Economic Development, and Miscellaneous. Second, a prompt for LLMs to automatically classify DAO proposals in the given categories. Third, a set of parameters for GPT-4.0 from OpenAI to receive consistent results in the classification.

We contribute to theory in two ways. First, by adding to the understanding of LLMs and their use for automatic data classification. Second, by providing a tested categorization of DAO proposals that can be used in future research. Furthermore, we contribute to practice by providing the complete prompt, parameters, and categories so that any researcher and practitioner can replicate our findings.

Our work acts as a starting point for in-depth research on DAO proposals. We foresee that quantitative and qualitative research on each proposal type will increase, leading to a deeper understanding of the dynamics and decision-making processes within DAOs. Future research can potentially assess the effectiveness of each proposal category and find bottlenecks in DAO governance.

Using the artifacts, we classified 1614 proposals and 3572 discourse discussions from Aave.eth, arbitrumfoundation.eth, balancer.eth, comp-vote.eth, lido-snapshot.eth, safe.eth, Uniswap.

7.4 Appendix - Prompt

The following is the title and description of a Proposal for a Decentralized Autonomous Organization (DAO).
Please analyze the following title and body of the proposal and classify it using the categories and their explanation that are listed afterward
TITLE: {Proposal Title}.
BODY: {Proposal Body}.
BODY END
You can ONLY choose from the following curated categories:
Categories: [TAM, PRM, PFU, GAFM, BAWM, PED, MISC]
Explanation: {Categories Explained}
Also answer the following question:
Does the proposal affect the personal stake or wealth of the voters? (true/false)
Use the following JSON template with example values to answer using a percentile how certain you are with your evaluation.
Replace y with at least one category shortcut, z with a reasoning, x with a number from 0 to 1. Additonally, for llm_categories, come up with at least one top level category that would fit the proposal in order for a researcher to later do clustering on them
Also perform a sentiment analysis and provide the values in the sentiment arrays.
Convert all price ranges to their average. Convert abbreviations like K=Thousand, M=Million to the responding full number.
ALWAYS respond with a valid json for python with the following structure:

```
{
  'personal_wealth_affected: false,'
  'most_relevant_curated_categories: ,'
  'clear_reasoning: z,'
  'categories: {'
    'TAM: x,'
    'PRM: x,'
    'PFU: x,'
    'GAFM: x,'
    'BAWM: x,'
    'PED: x'
    'MISC: x'
  },
  'llm_categories: ,'
  'risk_for_dao: number,'
  'total_cost: number $currency or false,'
  'total_revenue: number $currency or false,'
  'emotion_detection: [{example_emotion: 0.x, etc.}],'
  'fine_grained_sentiment: [{example_sentiment: 0.x, etc.}],'
  'professional_proposal_structure_score: number,'
  'previous_proposal: bool or id,'
  'is_recurring_proposal: bool'
}
```

7.5 References

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8 Discussion[48]

The thesis aimed to advance the theoretical understanding of DAOs in academia and help practitioners better understand and evaluate DAOs to build more effective DAOs in the future. It aligns with many essays that expand our understanding of DAOs using both qualitative and quantitative methods (Rikken et al. 2021; Hsieh et al. 2018; El Faqir et al. 2020; Faqir-Rhazoui et al. 2021; Filippi und Hassan 2016; Hassan und Filippi 2021; Hsieh et al. 2017).

Essay	**Contributions**	**Previous State of Knowledge**
(1) A Taxonomy of DAOs	Taxonomy of 20 dimensions and 53 characteristics	None
(2) Decoding DAOs	Comparison of practitioner scoring methods	None
(3) From Dissonance to Dialogue	Novel token based IS to improve recall communication	Non-token based IS for recall communication
(4) Network Analysis of DAOs	Presence of 90-9-1 rule; unequal distribution of voting power; scale-free network properties of DAO memberships and proposal participation	Unequal distribution of voting power; Studies on decentralization of DAOs
(5) Navigating the Research Landscape of DAOs	State of knowledge; Challenges and opportunities of DAO research; Details for working with DAO data; Novel research agenda	State of DAO knowledge; Research Agenda
(6) Classifying Proposals of DAOs using LLMs	Demonstration for using LLMs for augmenting datasets in a business context; Classification with seven categories of DAO proposals	Augmenting datasets in artificial intelligence and machine learning using LMs and LLMs

Table 8-I. Summary of findings and the current state of knowledge

Table 8-I shows the several research gaps that have been identified and solved in this thesis to reach the goal advancing DAOs, such as a taxonomy of DAOs, categorization of DAO proposals, knowledge of practitioner scoring methods, requirements for future DAOs, and

[48] This chapter is based on the six essays of this thesis

insights on the inner workings of DAOs, such as network properties and distribution of voting power.

The thesis excels on identifying the main dimensions and characteristics of DAOs by first identifying them on a DAO level and then on a proposal level. Both the taxonomy of DAOs and the categorization of DAO proposals are novel and the first of their kind in academia. For this, methods from design science research are mainly used (Peffers et al. 2007; Nickerson et al. 2013; Möller et al. 2020). This thesis also uses qualitative research methods such as content analysis and literature reviews (Kitchenham 2004; Finkbeiner 2017; Krippendorff 2019). Lastly, this thesis uses agglomerative clustering using the Wards method (Ward 1963) and cluster measures (Berkhin 2006; Dunn 1974; Pedregosa et al. 2011; Davies und Bouldin 1979). For the large-scale analysis, network properties (Barabási 2009) are analyzed using the largest data set of DAOs and proposals yet used in academic publications on the inner workings of DAOs. The individual methods and datasets used in each essay are displayed in Table 8-II.

Essay	**Methods**	**Dataset**
(1) A Taxonomy of DAOs	Iterative Design Science; Hierarchical Clustering	72 DAOs
(2) Decoding DAOs	Literature Review; Content Analysis	Three Scoring Platforms
(3) From Dissonance to Dialogue	Iterative Design Science	N/A
(4) Network Analysis of DAOs	Quantitative Data Analysis; Network Visualization	31,002 DAOs, 220,960 proposals, 51,987,413 votes, 154,087,070 token ownerships, and 46,695 historical governance token prices
(5) Navigating the Research Landscape of DAOs	Integrated Literature Review; Quantitative Data Analysis	59 Papers on DAOs; Dataset of essay (4)
(6) Classifying Proposals of DAOs using LLMs	Iterative Design Science; Data Augmentation with LLMs	1614 proposals and 3572 discourse discussions

Table 8-II. Summary of methods and datasets

The main motivation for the thesis is the rise of blockchain technologies in the last years and the use-cases such as DeFi, use-cases with NFTs, and supply chain tracking, which can all use DAOs to govern them.

8.1 Summary of Findings

Essay I presents a novel taxonomy of DAOs, with the main pillars of a DAO being *Community*, *Governance*, and *Treasury*. It further divides these super-categories into *Community Membership*, *Community Meta Information*, *Governance Token*, *Governance Process*, *Governance Voting*, *Treasury Meta Information*, and *Treasury Setup*. Each of these categories has its own dimensions and characteristics respectively. Further, inadmissible characteristics of DAOs are listed: *Has Governance Token: No*; *Has Governance Voting Process: No*; *Treasury is Public: No*; *Treasury Type: Single Owner or None*. Using a hierarchical clustering approach on the properties of DAOs, the essay finds five primary clusters of DAOs: *Off-Chain Product and Service DAOs with Community Focus*, *On-Chain Product and Service DAOs*, *Investment-focused DAOs*, *Networking-focused Community DAOs*; *Off-Chain Product and Service DAOs with Investor focus*. Lastly, the predominant characteristics for all cluster types are shown in Table 2-IV.

Essay II finds that the three scoring platforms, Prime Rating, DAO Meter, and DeFi Safety, have overlapping rating systems but different goals for their ratings. While Prime Rating focuses on the solution's novelty, its market fit, and the token's capabilities, emphasizing a protocol's value proposition, DAO Meter evaluates the maturity of DAOs, concentrating on the development background and security infrastructure of protocols, and DeFi Safety emphasizes security and bug mitigation especially related to flash loans in DeFi protocols. In their scoring methodologies, all three platforms have *security*, *documentation*, and *team assessment* as main categories. The subcategory *anonymity of the core team* and *public code repositories* is vital in all three platforms but weighted differently. DeFi Safety and DAO Meter both utilize *auditing*. Prime Rating and DAO Meter both take *admin key possession* into account.

Essay III introduces a new IS designed to facilitate communication between customers and manufacturers, especially in a recall process. The IS is built on design requirements, design principles, and design features mapped in Figure 4-VI, integrating traditional technologies like ERP systems with blockchain and token techniques to create a direct connection between the manufacturers and the customers, which are highly reusable for practitioners developing similar systems. It further presents a conceptualization of a new ERC token standard specifically for co-value creation between enterprises and customers, which is deployed on the Polygon Testnet Blockchain Mumbai and, therefore, publicly available open source.

Essay IV utilizes a data set of 31,002 DAOs, 220,960 proposals, 51,987,413 votes, 154,087,070 token ownerships, and 46,695 historical governance token prices to first confirm the presence of the 90-9-1 rule, which has previously been shown for online communities (Nielsen 2006) revealing that only 5.33% of all token holders participate in voting, while only 0.17% create new proposals, then it highlights the unequal distribution of voting power through a deciding voter analysis showing that in 86.3% of all proposals, fewer than 10 voters determine their outcome and that less than 20% of all votes influence over 60% of all proposals this is especially substantial, as only 5.33% of all token holders participate in voting. Then, the essay validates the scale-free network properties by fitting a power-law function to the degree distribution of DAO memberships and proposal participation, suggesting influential nodes within the network. Last, the essay finds that information diffusion in the sense of vote timing is uninfluenced by the connection among voters, as determined by their shared membership in DAOs.

Essay V serves as a literature review of DAO research and as a research agenda for further research. It first presents the efforts of scholars to advance the field of DAOs in recent years and then presents the evolution of DAO definitions over time and the change in scope and comments on common research goals such as measuring successful DAOs and decentralization, arguing that many scholars roughly performed the same measure under different names: *Herfindahl-Hirschman Index (HHI), Gini coefficients, n-top players, n=1 top player analysis*. Furthermore, it presents and comments on the most currently available data sources for researchers doing DAO research and gives help in interpreting and filtering this data. Finally, it represents a research agenda that suggests expanding the theoretical knowledge of DAOs in the direction of *Games, Players, and Institutions when analyzing proposals* and suggests *correlative and analytical models* examine statistical relationships between variables and give further insights into, for example, how token inequality affects the overall performance and decision-making efficacy within DAOs. Additionally, *financial risk simulations*, *economic simulations*, and further *specific theory developments* are highlighted as possible paths of research.

Essay VI makes two distinct contributions. First by designing novel categories for DAO proposals and second by demonstrating the effective use of data augmentation using Large Language Models for automating the classification of complex data sets. Using an iterative design science approach, the proposal categories *Treasury and Asset Management (TAM), Protocol Risk Management (PRM), Protocol Features and Utility (PFU), Governance Administration and Framework Management (GAFM), Budget Allocation and Work Management (BAWM), and Miscellaneous (MISC)* are created. Using GPT-4 (OpenAI et al. 2023) with a prompt to output the proposal category given a proposal title and body, it achieves a 95% accuracy in the classification of proposals compared to expert human labeling. To demonstrate the IS, 1614 proposals from Snapshot and 3572 discussions from discourse taken from the aave.eth, arbitrumfoundation.eth, balancer.eth, comp-vote.eth, lido-snapshot.eth, safe.eth, Uniswap, and the automatically classified.

8.2 Implications for Theory and Practice

Each essay in this thesis makes a distinct contribution to both theory and practice around DAOs. Essay I provides a non-intuitive data-driven taxonomy that can be used for further research and the creating or fine-tuning of DAOs. It further contributes to the descriptive knowledge of a new research area by providing technical descriptions. The presented clusters allow researchers to target a specific type of DAO for their analysis instead of looking at all DAO types the same. Essay II contributes to practice by presenting existing scoring methodologies, for researchers and practitioners to create their own scoring methodologies.

Essay III contributes to practice by first proposing a new token standard that can improve the efficiency of the effectiveness of recall communication for enterprise goods and, second, exploring how blockchain technology can be used to connect enterprises with customers to directly inform and involve them in the recall process allowing for improved communication and collaboration such as receiving faster and more personalized case-related information. Third, it shows how to integrate new technologies into existing systems with minimal effort with blockchain identifiers. Furthermore, Essay III also advances theory around blockchain-based systems by conceptualizing a new ERC Token standard and by showing what use cases DAOs need to be able to govern in the future.

Essay IV contributes to theory by connecting online communities and their theories with DAOs by conducting four empirical studies and analyzing certain properties existent in online communities in DAOs. It also contributes to practice by revealing huge inequalities in voting power that lead to a power concentration that must be solved in future generations of DAOs. Essay V contributes to practice by summarizing and commenting on existing research and putting up a research agenda that DAO researchers can use for further work in the field, but it also contributes to practice by showing how to retrieve and filter data.

Lastly, Essay VI contributes to theory by giving researchers tangible categories for DAO proposals to work with and contributes to practice by showing how to automatically retrieve the categories from DAO proposals using LLMs.

8.3 Directions for Future Research

As this thesis touches on many cutting-edge topics that are not yet well-researched, this section will provide a comprehensive overview of all areas touched on in this thesis and how to expand them.

First, the taxonomy of DAOs needs to be expanded as new generations of DAOs are created as it is designed in a way to be easily expandable for other researchers. Second, DAOs need to be evaluated further on different metrics. The next chapter describes a possible evaluation of DAOs in detail.

8.3.1 Evaluating DAOs

While many metrics are important such as the decentralization, governance activity and lots of others, research into especially three key metrics should be conducted:

- Cost of Governance
- Effectiveness of Governance
- Lobbying and Collusion

Analyzing the cost of governance is the first step in evaluating a DAO. As with every organization, governance incurs a cost. With DAOs, this cost is not mainly paid by the DAO itself but also by other organizations. In addition to this, there are also intrinsically motivated individuals who do not get paid for their governance. The contributors are, therefore, divided into three parts: Directly paid, indirectly paid, and intrinsically motivated contributors. Further research should, therefore, study how much time each group spends on governance, particularly on each proposal, and how much money each group receives for their work. With this intended framework, the cost of each proposal, combined with proposal categories, can serve as a starting point for understanding the operational costs of governance for each DAO.

Next, further research needs to determine the effect each proposal has on a DAO's treasury or public relations. For example, when a DAO allocates $10000 for a project, and the DAO receives back 12000$ after 1 year on the investment, the cost of governance needs to be subtracted to evaluate if the time spent on allocating this money and the operational overhead was worthwhile for the DAO. Therefore, the monetary effect of each proposal needs to be determined. This research should specifically not look into the indirect effect of proposals on the governance token price, as too many variables influence this. Combining the cost of governance and the outcomes of proposals would allow researchers to score each DAO's effectiveness of governance, showing practitioners what properties a well-run DAO should have and, based on this, improve the structures of existing nonefficient DAOs.

This strategy would be optimal for determining the effectiveness of governance in DAOs; however, obtaining the exact monetary outcomes of each proposal and determining how much money is spent on governance is extremely challenging. Therefore, researchers could also first design a new scoring framework that uses proxies that are easy to gather and describe the effectiveness, performance, security, decentralization, or other properties well enough. The thesis has presented the inner works of different scoring platforms that can be used as a starting point.

Last, lobbying and collusion should be investigated, as discussions on DAO governance also happen in private Telegram groups, Discord Servers, or other nonpublic platforms and not only on public pages such as their discourse forum and Snapshot. This makes it hard for researchers to directly correlate discussion and voting activity, as it is always unknown, what happened in the background. This is important to understand the governance processes and the effort put in by individuals to convince voters or delegates for or against a decision. Using this analysis, researchers might be able to explain non-rational decisions on some proposals.

8.3.2 Analyze Network Dynamics

There has been little to no research about influential actors in the DAO space. DAOs such as MakerDAO have been using a delegate system for years, where tokens are delegated to only a few addresses that hold the power over the complete protocol. There is no research on their motivations for taking part in the governance. The unequal distribution of governance and voting power present in the wealthiest DAOs suggests a concentration of power in a few individuals or companies. Therefore, *lobbying and collusion* should be studied further to understand if the power is concentrated within a few individuals or companies and combined in a cartel.

Additionally, non-profits and academic institutions or student clubs are actively shaping governance. An analysis of their motives, voting behavior or comparison to for-profit actors does not yet exist.

8.3.3 Designing new DAO Types

More design science research is needed to conceptualize new DAOs that are capable of governing, for example, the proposed recall communication system. However, this IS should not be designed specifically for this use case but for a broad range of new DAO types governing previously centralized platforms such as social media platforms, video or game streaming platforms, music streaming services, etc.

Upon identifying the cost of governance and the governance performance of existing DAOs, those insights should be used to create more effective DAOs from scratch.

8.3.4 Data Augmentation

Data augmentation using pre-trained LLMs has only recently gained traction in computer science but has not yet been utilized to its fullest in information systems or economics. This application of LLMs helps researchers to gather contextual data quicker and enables a single researcher or a small group to perform studies previously only possible with huge resources and teams. In regard to DAOs, the prototype for classifying DAO proposals should be expanded to also work with self-hosted LLMs and not only the API of OpenAI; additionally, more categories and insights than the ones proposed in this thesis can be gained from proposals when combining augmented data from several DAOs together.

8.4 Limitations

This thesis has two limitations on the impact of the findings. One being data availability and the other data quality. While Essay I is based on a dataset of less than 100 DAOs that were analyzed qualitatively and, for example, filtered by inadmissible characteristics such as a treasury owned by a single address, Essay IV uses a data set of more than 30,000 DAOs where we did only filter by attributes retrieved by Snapshot such as *flagged* and the *network IDs* to filter out spam. Ideally, each DAO and proposal should have been checked for validity for not being a test-proposal, spam proposal, or malicious. This is, however, unrealistic, with a dataset of more than 220,000 proposals.

8.5 Concluding Remarks

Overall, this thesis aims to advance the theoretical and practical understanding of DAOs in the academic community of this new organizational form and type of online community. This goal is achieved in six different essays, each covering a unique angle of DAO research. It presents a novel taxonomy of DAOs, a categorization of DAO proposals, an information system for recall communication, an analysis of DAO scoring methodologies, and a large-scale analysis of DAOs, analyzes past research, and presents many open research questions to be answered by scholars about DAOs, therefore making many novel and high impact contributions to the field of DAO research.

8.6 Discussion References

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