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Unraveling the definitions, characteristics, and emerging developments of DAOs

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Research Article

The ins and outs of decentralized autonomous organizations (DAOs) unraveling the definitions, characteristics, and emerging developments of DAOs

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ABSTRACT

Despite the increase in the number of blockchain-based Decentralized Autonomous Organizations (DAOs), there is no consensus on what constitutes a DAO. This paper provides an in-depth study of DAOs by analyzing their definitions, characteristics, and emerging developments. Existing definitions in the literature hardly recognize common functionalities and intermingle coded DAOs, DAO deployment platforms, and blockchain DAOs. We developed a comprehensive DAO definition by reviewing the literature and empirically analyzing 1,859 DAOs. The findings show that many DAOs were inactive and that a threshold of 20 tokenholders is a tipping point for DAOs to survive over time and maintain sustained levels of activity. Finally, based on an empirical analysis of 9,845 perceived DAOs, we identified the emerging development of off-chain voting. This emerging development challenges the autonomous nature of DAOs. We recommend further research to investigate the effect of governance structures on their long-term sustainability and viability for both on-chain and off-chain DAOs.

1. Introduction to decentralized autonomous organizations (DAOs)

DAOs are blockchain-based applications for the automated execution of governance processes. DAOs were first referred to as a 'coded organization' by Larimer [1]. The code automates a large part of the governance of the organization, and humans are no longer actively needed to execute operations. In this way, DAOs can automate transactions, operations, and decision-making by organizations.

DAO governance is decentralized by nature since the use of blockchain ensures that there is no need for central execution. The governance of a DAO often consists of participants casting their votes. After that, the decisions are automatically executed without the need for a trusted third party (TTP) or a central authority (e.g., a notary) to ensure the integrity or guard the content of the data [2,3]. This creates a new way of organizing, managing, and governing organizations.

In the first generation of blockchain infrastructure protocols (e.g., Bitcoin, which was first introduced in the 2008 Bitcoin whitepaper by Satoshi Nakamoto [4]), it was difficult to include any decentralized logic in transactions. However, the advancement in the second-generation infrastructure protocols (e.g., Ethereum and Hyperledger) has made this substantially easier. The infrastructures cater to smart contracts or chaincode creation and functionality [5]. Smart contracts are coded on, deployed on, and executed by blockchain [6–8]. As such, blockchain-based smart contracts are accounts that can store and execute business logic described by code in a decentralized way. Hence, these can be used as building blocks for DAOs [9]. Due to this additional functionality in the second-generation blockchain infrastructure protocols, there is an upsurge of blockchain-based decentralized applications [10].

In blockchain-based decentralized applications, direct and conditional transactions are possible. The direct transactional application uses the blockchain to record the transactional outcome of the use of the application. This means that the transaction is recorded directly on-chain based on the transaction request from a wallet and/or read from the blockchain adhering only to the rules of the off-chain part (wallet) and the blockchain protocol core software. In contrast, a conditional transaction application has parts of its code and the execution logic embedded in the blockchain through smart contracts. Such a transaction requires

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interaction between a wallet and a smart contract (where part of the logic is embedded), adhering to the entire rules of the off-chain part, the smart contract code, and the blockchain protocol core software. Conditional transactional applications are often used for creating DAOs [11].

Although the rise of these protocols led to the first experiments with DAOs, the possibilities of DAOs only gained more exposure to a broader audience with the creation and the hack of "the DAO", which is the first large-scale DAO implementation [12,13]. The number of perceived DAOs has risen exponentially over the years, particularly during the period 2018–Q3 2022, as shown in Fig. 1. Note that we use the term 'perceived', as there is no consensus on the exact characterization of a DAO. Moreover, diverse definitions of DAOs exist in practice and the literature [14]. However, there is no unifying definition [15]. As a result, there is unclarity regarding whether a blockchain application initiative can be qualified as a real DAO, how a DAO is set up, or what the functional purpose of a DAO is. This unclarity about what constitutes a DAO makes it difficult to determine how many DAOs exist.

Existing research focuses predominantly on either approaching DAOs from a descriptive, theoretical perspective [16–19] or analyzing a single or small number of DAOs or certain events like "the DAO incident" [13, 20–24]. Other studies focus on literature reviews and the ontology of DAOs or the legality of smart contracts in DAOs [25,26]. Few but a rising number of studies have conducted somewhat larger empirical research on DAOs. El Faqir et al. [27] estimated the number of DAOs by analyzing only one particular DAO type (i.e., DAOstack). The limited number of studies of DAO governance mainly analyze governance at a general level, relating it to corporate or IT governance and not specifically to the decentralized governance of DAOs [28–31], by looking into DAO platform selection criteria [15] or DAO forks [32]. Additionally, only a few studies on DAO governance focus on the voting power distribution within DAOs [33], the differentiation in governance tasks, and the effect on operational performance [34], where a smaller set of use cases were empirically analyzed. Thus, there is a lack of in-depth empirical studies of DAOs with a large dataset.

Considering the abovementioned research gaps, this paper aims to (1) develop a comprehensive definition of DAOs, (2) examine the decentralized characteristics of DAOs, and (3) analyze emerging developments and their potential implications for the existing DAO definitions and characteristics. For the first aim, we analyzed both scientific and gray literature. In addition, we performed an in-depth empirical analysis of 1,859 perceived DAOs to find the key characteristics of DAOs. This empirical analysis was also used to examine the decentralization characteristics of DAOs (the second aim). To identify emerging developments, the previous 1,859 DAOs and an additional 8,000+ perceived DAOs (9,845 DAOs in total) were analyzed.

Accordingly, the three aims of this paper result in three main contributions. First, as there is no consensus on what constitutes a DAO, we crystallize and develop a comprehensive definition of a DAO based on a set of characteristics derived from the existing DAO definitions supplemented with the key characteristics as found in our empirical analysis. Second, considering that DAOs are often only decentralized in name but not in practice [35], we examined the influence of the number of tokenholders for a DAO to survive over time by performing a survival analysis of the number of tokenholders and its relationship with the activity level (survivability) of DAOs. This provides the first empirical evidence of the minimum level of decentralization in DAOs. Third, we analyze emerging developments that can influence and even challenge the existing definitions and characteristics of DAOs.

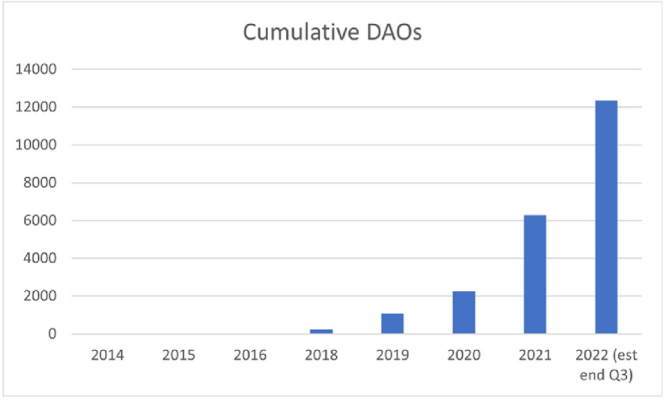


Fig. 1. Perceived decentralized autonomous organizations (DAOs) over time. (Note: The term "perceived" is used here due to the unclarity in current definitions regarding what a DAO really is.)

This paper is structured as follows: In the next section, the research methods used are described. Section 3 presents the literature review and an in-depth analysis of DAO definitions and characteristics. This analysis results in a unified DAO definition. Section 4 covers the results of our DAO empirical analysis, a categorical analysis of DAOs, a survivability analysis, and the minimum level of decentralization. Here, an overview of all potential and self-proclaimed DAOs is subsequently categorized. The analysis of emerging developments is presented in Section 5. We end the paper with key conclusions and recommendations for follow-up research.

2. Research approach

To answer the first question, we reviewed the existing definitions and characteristics of DAOs through a systematic literature review [36]. We used the following keywords to search in Google Scholar: "blockchain", "governance", "decentralized autonomous organiz(s)ation", "DAO" and their combinations (November 2019–January 2023), and a long-running daily Google Alert service (keyword "Decentralized Autonomous Organization", November 2020–January 2023). After screening for the relevant literature, we obtained 75 articles (papers, blogs, webpages, and transcripts) with a total of over 600 pages. Fig. 2 shows the decomposition of the number of papers over the various categories. Of the reviewed literature, 61 papers have DAOs as the main topic. In the remaining 14 articles, DAOs are not the main topic but are mentioned and discussed in one or more parts as part of a broader discussion or research. Of the 61 articles having DAOs as the main topic, four specifically focused on "the DAO" incident or hack in 2016, whereas the remainder of the 57 articles focused on DAOs in general, discussing various elements, from definitions to governance.

Besides reviewing the literature, to address the first research question (comprehensive definition and characteristics), we empirically analyzed the characteristics of 1,859 DAOs (Table 1). The 1,859 DAOs were collected by using various DAO websites and Google searches on "DAO" or "Decentralized Autonomous Organization(s)" and Google Alerts on "Decentralized Autonomous Organizations". From the 1,859 DAOs, 1,635 DAOs were analyzed based on functional and implementation characteristics. This was needed because out of the initial 1,859 DAOs, only 1,635 DAOs actually had active individual web pages where on-chain activities (the activity level and functionality offered by a DAO) were monitored.

For each DAO, we documented the individual link to the unique website of that DAO, analyzed all the (sub)pages and activities, manually counted the number of tokenholders and amount of public voting (proposals), and examined various characteristics. If no unique websites were found, the activity and tokenholders were tracked via block-browsers (e.g., etherscan.io) using the DAO smart contract addresses or via the installment of dedicated block-browser apps (e.g., Bisq). This is a laborious process, as it took 2–10 min to gather all the required details for each DAO. For the long-term viability analysis, we even had to revisit each DAO multiple times to record the change in activity over time.

To answer the second research question (examining the decentralization characteristics of DAOs), we analyzed the 1,859 potential DAOs using 14 different blockchain infrastructure protocols. Here, we analyzed these DAOs individually based on a number of characteristics: name, year

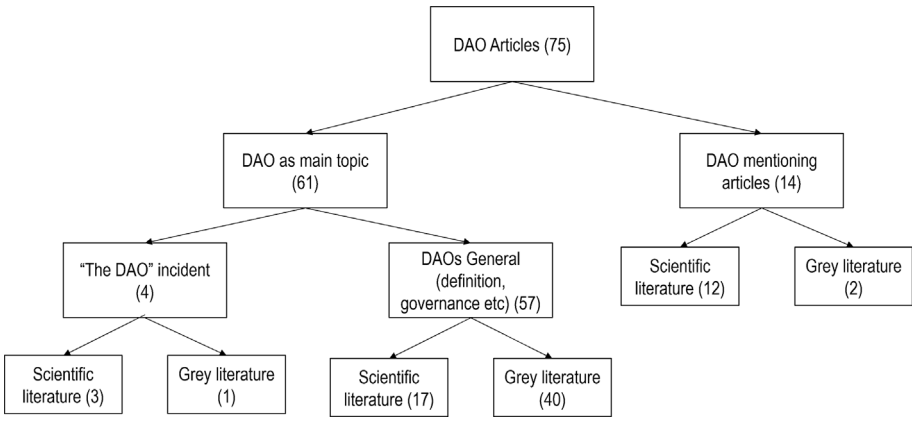


Fig. 2. Literature breakdown (number of hits is shown in brackets).

Table 1
Research data.

Research question	Type of data	Search period	Data	Sources (links)
RQ1 Developing a comprehensive definition	Scientific literature (papers) and gray literature (blogs, transcripts, and webpages)	Until Jan 2023	600+ pages	Google Scholar, blog links (e.g., medium.com and hackernoon.com), and Google Alert
	Blockchain protocols	Until Jan 2023	14 blockchain infrastructure protocols	Not applicable
RQ2 Examining the decentralization characteristics of DAOs	First batch of perceived DAOs	Nov 2019–2 July 2021	1,859 perceived DAOs	apiary.1hive.org, aragon.org, dauhaus.club, daostack.io, pokemol.com, etherscan.io, colony.io, scout.cool, district0x.io, and links to various individual DAOs, Google Alerts
RQ3 Analyzing emerging developments	Second batch of perceived DAOs	3 July 2021–30 June 2022	9,845 perceived DAOs, i.e., the 1,635 DAOs from the first batch plus 8,210 additional DAOs	Same links as the first batch and additional links from snapshot.org and boardroom.info, Google Alerts

Note: The full datasets are available at http://doi.org/10.4121/edfa3d4c-f347-4a79-b8fb-c80e9cb385de.

and month of creation, status, how each DAO was built, and the blockchain infrastructure protocol the DAO was built on. Furthermore, we recorded the functionality of those DAOs by manually opening all the individual/dedicated sites of the DAOs where the on-chain data were presented. We counted the number of participants in the form of tokenholder accounts in each DAO, the number and amount of cryptocurrencies and tokens on the balances in the treasury of the DAO, and its activity in the form of public voting (proposals). We analyzed the activity level over time, i.e., the change in the number of tokenholders (new accounts holding tokens or accounts no longer holding tokens), and the transfer of value from and to the treasury and public proposals. Individual votes by tokenholders on proposals were not included in counting the number of activities. To observe any changes during this period (in continued or discontinued activity), we examined the same group of DAOs six to fifteen months later. Furthermore, a quantitative analysis in the form of a statistical survival analysis was performed to investigate the tipping point at the level of the core number of tokenholders for ensuring the long-term viability of DAOs (activity levels). The analyses help to understand the relationship between the number of tokenholders and the viability (activity level) of DAOs, thus quantifying a part of decentralization in DAOs.

Finally, to answer the third research question (i.e., analyzing emerging developments), we performed a literature study of the emerging developments (based on the same literature used for addressing the first research question). We combined this with empirical research into a total of 9,845 perceived DAOs by comparing the growth in the different types of DAOs, following the same methodology as described for the first research question.

3. DAO definitions and characteristics

There is a steep rise in the number of perceived DAOs over time, as shown in Fig. 1. This number is disputable, as DAOs are ambiguously defined [14,15]. Ambiguous DAO definitions may lead to some confusion over whether a certain organization is a DAO or not. Clarity in the DAO definition is important for both users and researchers. For users, what defines a DAO can have consequences on their decision if they would like to participate in such an organization, whereas for researchers, conceptual clarity is key for understanding and analyzing an empirical situation.

As DAOs are multifaceted, various definitions approach DAOs from different perspectives, ranging from functional, organizational form, and purpose perspectives to technical creation, setup, and scientific and practical perspectives. There is no clear consensus about what makes up a DAO in the literature [14], which can be attributed to its emerging nature. In the next subsection, we discuss the similarities and differences in the definitions and characteristics of DAOs by summarizing and developing the functional and technological perspectives of DAOs. We then analyze the extracted and observed characteristics to identify the most common characteristics in the existing definitions. We create a comprehensive definition by combining these common characteristics with the observed characteristics in our empirical research.

3.1. Functional and organizational form (or purpose) perspective

There are various terms related to DAOs. In 2013, Daniel Larimer first coined the concept of DAOs in his post on the hidden cost of Bitcoin, where he proposed the term Decentralized Autonomous Corporation (DAC), i.e., an organization with coded bylaws, a limited amount of services, and a goal to generate profit for its shareholders [1]. Buterin [9] described the DAC as a subversion of the DAO, as the purpose of DAOs can be more general and does not necessarily have a financial purpose. Buterin also described smart contracts as the building blocks for DAOs instead of a fully running blockchain network.

In 2018, the concept of DAICO was introduced by Vitalik Buterin [37]. The acronym is actually a combination of DAO and Initial Coin Offering (ICO). This type of DAO is designed to improve the ICO model by introducing governance elements around the transfer of value of a DAO [37]. Another DAO type was also described in the same year, i.e., the Decentralized Autonomous Co-Operative (DACo) [38]. The DACo is set up to control the new digital commons, where collective decentralized behavior is incentivized to establish an organization with a common good in mind and for non-profit [38].

After DAICO and DACo, the Limited Liability Autonomous Organization (LAO) is another variant related to DAOs. LAO is another generation of DAO where the Ethereum environment is bridged to traditional legal regimes. These DAOs focus on setting up legal entities, providing legal structures, and binding legal agreements [39]. One of the most recent DAO subtypes is the Decentralized Party (DePa). DePa is considered a political party that operates like a DAO to establish transparency and clear accountability [40].

DACs, DAICOs, DACos, LAOs, and DePas all make use of the overall concept of DAOs. Fig. 3 shows that they can be considered a DAO specialization.

3.2. Functional characteristics in practice

We further analyzed the key functionalities for each of the DAOs. This enabled us to determine the common functionalities offered by DAOs. Functionalities include the storage of links to information, chat functions, agents (links to other smart contracts external to the DAO), allocations, addresses, dot votings (which are multiple option voting instead of binary option voting), rewards (dividend payments for tokenholders), and projects. These functionalities are all predominantly available in Aragon-based parameterized platform DAOs (see Section 3.3) [41,42]. Other DAO templates (e.g., Moloch through the DAOHaus parameterized platform) offer ragequit functionality. Ragequit refers to the ability for members to exit at any time with a proportional amount of funds to ownership [43,44]. Two key functionalities are consistently shared by almost all DAOs:

1. **Storage and transfer of value functionality.** The vast majority of DAOs analyzed have the ability to store and transact value as a result of a certain trigger, such as a decision outcome or an incoming transaction, in the form of cryptocurrencies or tokens. The total value stored and controlled by DAOs is estimated to have surpassed US $6 billion [45].
2. **Trusted notary functionality.** Nearly all of the observed DAOs have the functionality to organize, track, execute, and archive voting. This trusted notary function is often the trigger for the transaction of value, i.e., executing the transaction once the vote has reached a certain threshold.

Of the 1,635 DAOs analyzed, 96.3% contained both characteristics, 99.0% contained at least one of these two, 0.7% contained other or no functionality, and 0.3% of the functional purpose was unclear. These functional characteristics are not always described in the existing literature [14,18,46], while others do describe them [12,47]. These two characteristics are found in almost all DAOs, and without them, DAOs lose their primary functionality. Hence, we consider both characteristics vital for DAOs.

3.3. Technical creation and setup perspective

Apart from functional differences, some differences in DAOs are inherent due to the implementation of DAO applications. From a technical view, the existing literature refers to both blockchain infrastructure protocols and smart contract applications as DAOs. Ziolkowski, Miscione, and Schwabe [48] mention DAO platforms, such as Aragon, DAOStack, and DAOHaus, as being a DAO or a governance platform, while strictly speaking, these platforms only enable the deployment of DAOs. Standard DAOs can be created on these platforms based on a fixed number of templates. Previous literature [14,27] distinguishes between typologies of DAOs, but often in only two groups, either self-coded or platform-based. The team of the Dash project [49] argued that blockchains in themselves can be seen as DAOs. However, this would not result in any distinctive features, as blockchain is the platform on which the DAOs (and other applications) are developed. Based on the descriptions in the literature and our analyses, the subtypes of DAOs are visualized in Fig. 4.

The various potential DAOs can be divided into two main subtypes: (1) smart contract-based and (2) full blockchain protocols. This distinction is important because it can have significant consequences for the DAO's governance due to the entanglement between application and infrastructure [11]. With blockchain-protocol-based DAOs, the blockchain protocol is the DAO in itself. As this is the case, the DAO and infrastructure are assumed to have the same governance group. There is no entanglement between DAO application governance and infrastructure governance. However, as smart contract-based DAOs are deployed on an existing blockchain infrastructure, the governance of the application can become dependent on the governance structure of the infrastructure [11]. "The DAO incident" is a clear example of the entanglement of the application and the infrastructure level, which eventually led to the hard fork of the infrastructure as a result of a flaw in the application. There are various examples of blockchain protocols of DAOs, such as Decred, Steemit, NAVcoin, and BOSAGORA, in which voting is done by native cryptocurrency, tokenholders, or node owners [18,50–52].

Subsequently, smart-contract-based DAOs can be divided into two main groups: self-coded (or self-built) DAOs and parameterized DAOs. Self-coded DAOs are completely built and deployed by the DAO owners themselves. Parameterized DAOs can be further subdivided into two subgroups. The first subgroup makes use of platforms such as Aragon, DAOHaus, or DAOStack. For deployment, there are fixed templates for the type of DAO one wants to implement. Users only have to fill in a limited number of variables (no coding needed). The second subgroup uses precoded DAOs by copying the code from GitHub and deploying it themselves (like EOSDAC). In sum, all these subtypes have obvious consequences on the possible functional uses and their respective governance mechanisms.

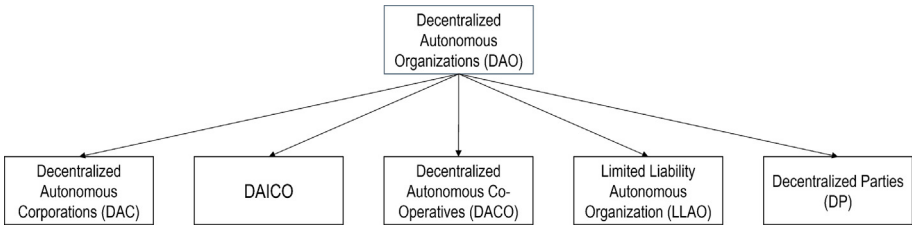


Fig. 3. Decentralized autonomous organization (DAO) subtypes.

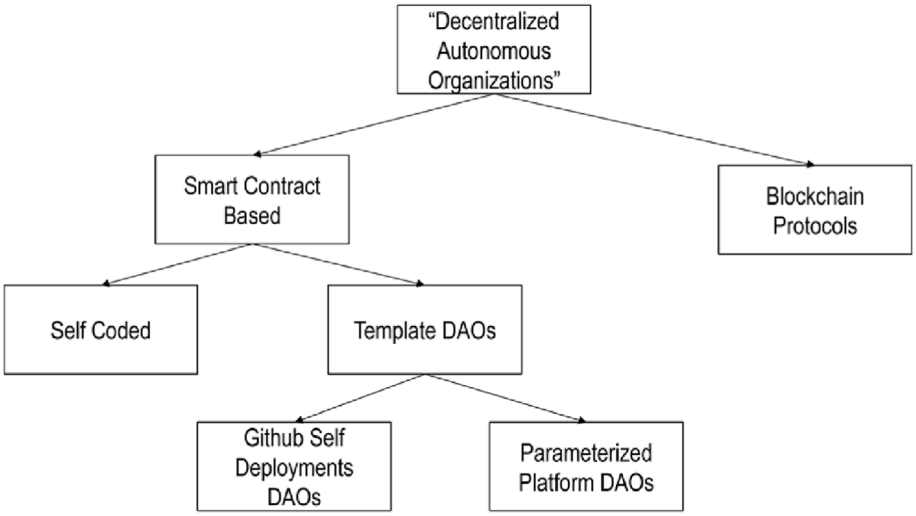


Fig. 4. Breakdown of types of DAOs based on technology and deployment type.

3.4. DAO definitions in the white and gray literature

There have been various attempts by scholars and business practitioners to define DAOs. Although the existing definitions show some commonalities, they still differ, resulting in complex and ambiguous interpretations of a DAO. We deliberately analyzed definitions from both scientific literature and gray literature (business reports), as they can provide valuable theoretical and practical insights.

3.4.1. DAO definitions in the literature

Through a literature review, we identified 13 relatively unique definitions of DAO (see Table 3). Several authors cite existing DAO definitions and follow or build on each other's definitions. Kypriotaki et al. [53] described DAOs as decentralized entities using blockchain to run their activities autonomously and decentralized. They further pointed out that decision-making is done by coded logic through the use of smart contracts. As decision-making is automated, this creates value for their customers. This definition is also adopted by Kondova and Barba [54].

In 2018, Hsieh et al. [16] described DAOs as organizations that organize themselves through a democratic process. This is done on a public peer-to-peer and cryptographically secured network but is not necessarily referred to as blockchain or smart contracts. They emphasized routine tasks and the idea that DAOs rely on voluntary contributions from the stakeholders of the respective DAO for all lifecycle stages (operating, managing, and evolving). They also mentioned that the code should be open source [16]. With this definition, they followed the previous works of Dietz et al. [55] and Van Valkenburgh et al. [56]. Zwitter and Hazenberg [57] further followed the descriptions of DAOs by Kondova and Barba [54] and Hsieh et al. [16].

DuPont [28] described the DAO from "the DAO incident" perspective. He specifically mentioned that a DAO is a new form of organization that is run on a public blockchain and that the governance roles are encoded in smart contracts, creating new forms of social interaction and order. Next, Diallo et al. [46] defined a DAO as a system that runs on a blockchain in a decentralized way but without specifying exactly what this decentralization entails. They mentioned that pre-defined rules are used to control the operations.

According to Diallo and colleagues, a DAO should be immune to internal and external attacks and much more robust due to the reduction in human processes [46]. In 2019, Zachariadis et al. [47] described a DAO as a distributed autonomous organization. They emphasized that blockchain can replace functions, such as voting and various forms of value transfer, with blockchain-based code and execution [47]. In the same year, Wang and colleagues defined a DAO as an organization based on smart contracts on a blockchain where the management and operational rules are coded. A DAO can operate autonomously without central control or intervention possibilities. A DAO challenges hierarchical models and should lead to efficiency gains on various points, such as collaboration, decision-making, and communication [18].

In 2020, Hassan and De Filippi conducted a brief review of DAO definitions [19]. They concluded that a DAO is blockchain-based, using self-executing rules on a public blockchain. They also mentioned that there should be no central control and that governance is decentralized, enabling people to self-govern and coordinate themselves. They asserted that the exact meaning of the terms 'decentralized' and 'autonomous' in DAO is still very much debated. The terms can either mean that decentralization and autonomy in DAOs only refer to the infrastructure level (i.e., being built on a blockchain infrastructure) or that DAOs are also decentralized and autonomous on the application level, meaning that decisions and executions are made through a democratic process or decentralized governance setup without a central authority or power. So far, regarding decentralized setup, a minimum level of participants in the process is unknown [16,19]. This will be discussed in more detail in Section 4.2.

More recently, Bellavitis et al. described DAOs as collectively owned and managed organizations. Using blockchain-based smart contracts for coded rules, DAOs enable members to propose and vote on any corporate type of decision for various purposes [58]. Various other researchers and scholars have used definitions with overlapping elements: from a decentralized system for operation and governance [20] and conditional transactional applications without a formal structure built on smart contracts and operating as programmed where human interference is limited [11] to autonomous execution of decisions made by consensus of the tokenholders [26].

3.4.2. DAO definitions in the gray literature

In the business context, there are various definitions of DAOs. In the 2013 Ethereum Whitepaper, Buterin [59] described a DAO as a virtual entity where participants, either members or shareholders, can vote on the allocation of funds and updates of the code. Incentives are provided through bounties, salaries, or internal tokens. In this context, the DAO can look like a traditional legal company but use blockchain technology for enforcement [59].

The 2016 "the DAO" whitepaper by Jentzsch [12] provided a broad description instead of a clear definition. He stated that the definition of DAOs is subject to much debate, particularly concerning legal status and ownership. A pertinent discussion is about whether DAOs need to be operated by humans, by human-created entities, or autonomously (run

completely by code). Jentzsch further argued that the answers to those questions depend on various circumstances. In principle, the DAO is set up to automate governance decision-making [12]. The whitepaper describes that the functionality is around storing and transferring value and has basically no other functions. If other functions need to be performed, a contractor needs to be put in place. Through a proposal, a contractor can ask for transferring value out of the DAO after approval by the DAO members. Such code can run via smart contracts on the Ethereum blockchain [12].

The parameterized DAO creation platform, Aragon, emphasizes in its manifesto the creation of true sovereignty that DAOs create [60]. Furthermore, Aragon emphasizes the change in governance relationships by moving towards an opt-in (participatory) environment. The participants are both in control of decisions and execution for others, which is possible due to decentralized technologies without the need for a third party.

In 2019, Honigman [61] described a DAO by dissecting the words. The DAO is autonomous (due to self-enforcing program operating rules), running on a public permissionless blockchain where value can be immediately transferred, and rules are enforced as a result of a decision. Decentralization can be interpreted in two ways: first, as a result of running on a blockchain, and second, as a lack of hierarchical organization with executives and shareholders. Decentralization can be within an organization or a whole organizational network.

There are various similarities and distinct differences in the various definitions derived by scholars and industry practitioners. Our findings show no clear differences in how the scientific literature and industry look at DAOs; they seem to echo each other. To obtain a more unified overview, we created an overview of DAO characteristics.

3.5. Overview of DAO characteristics

The various definitions of DAOs entail a wide range of DAO characteristics. Together with general blockchain characteristics such as transparency, decentralization, and cryptographic security, Hassan and De Filippi described online coordination, self-governance, blockchain-based, using smart contracts and coded rules for interaction, self-execution, and independence from central control as the most distinctive characteristics [19]. Samman and Freuden considered independence, transparency, and decentralization as DAO characteristics [17]. Cash identified seven characteristics or features of a DAO: autonomous, decentralized as in equal rights for each member, organized, smart contract-based, having a token for financing or transfer of value, and based on blockchain technology and open source code [62]. In 2019, Kondova and Barba [54], followed by the Consensus team in 2021 [63], identified transactions of tokens or cryptocurrency, autonomous execution, consensus, contractors, proposals, and voting as key elements of DAOs. Pranata and Tehrani also mentioned autonomous execution as a key element [26]. In our empirical research, we observed two main functional characteristics of DAOs: the transfer of value and a notary function (Section 3.2). So far, although there is overlap in key characteristics, there is no comprehensive categorization of these characteristics.

Based on the various definitions described, characteristics described in the literature, and analyzed characteristics during our empirical research, we define the following categories of characteristics:

- *Functional* characteristics: characteristics of DAOs focus on the functional side of DAOs in themselves, being the most common functionalities.
- *Governance* characteristics: characteristics that describe decision setup, making, and execution.
- *Technical* characteristics: characteristics based on the technical setup of DAOs.
- *Other (operational and legal)* characteristics: characteristics that either describe a specific operational element of DAOs or propose a legal form.

Table 2 shows the detailed characteristics of each of the four categories.

3.6. Mapping of definitions and characteristics to derive a comprehensive DAO definition

In Sections 3.4 and 3.5, we identified a wide set of characteristics related to DAOs, a wide range of DAO definitions, and key functional characteristics. We synthesized the characteristics from the described definitions and analyzed which characteristics are found in which definitions. This is shown in Table 3. When a characteristic is mentioned in the definition, a green color is given, while the orange color is given when only partially matched. The red color is given when there is no matching.

From Table 3, it becomes clear that none of the existing definitions contains all characteristics. The most commonly mentioned characteristics (e.g., with the most matching in green/orange) are decentralized at the infrastructure level (11 green/2 orange), often specified as blockchain-based, decentralized at the application level (5 green/6 orange), and decisions being made and/or executed autonomously (2 green/7 orange).

The essential functional characteristics of DAOs of both notary and value functions exist in almost all analyzed DAOs (as stated in Section 3.2, of 1,635 DAOs, 96.3% contain both, and 99.0% contain at least one of these two). Surprisingly, these functionalities are hardly mentioned in the existing definitions of both academia and industry, whereas they determine the general purpose or use of DAOs. Interestingly, the notary

Table 2
Description of the four categories of DAO characteristics.

Functional characteristics
• (Conditional) storage and transfer of value: The storage and transfer of value in these cases are always in the form of cryptocurrencies.
• Notary function for decision-making: This functionality refers to the element of being able to organize, track, and archive voting. This is typically where a DAO differs from any multisig application.
Governance characteristics
• Decentralized on the infrastructure level: Functionalities and rules are coded on blockchain (no one entity can stop infra).
• Decentralized on the application level: not in the hands of a single person/party that can make all the decisions.
• Autonomous decision-making: fully autonomous decision-making based on information presented.
• The organization and its code are fully transparent.
• Stakeholders reach consensus on decisions by voting based on predetermined voting rules (majority, quorum, and no hierarchy).
• Updates, bugs, and optimizations need democratic voting and decision-making by share/tokenholders.
• The decision-making process always starts with a proposal or external trigger.
• Voting rights could be distributed either based on the number of tokens owned or evenly.
Technical characteristics
• Smart contract code: This characteristic is described various times in different literature. There are multiple blockchain protocols (not applications often called protocols, like DeFi solutions call themselves) that consider themselves DAOs as well.
• The code is open source.
• Is (public) blockchain-based?
Other characteristics
• Operational: Two main characteristics
• Autonomous execution: A DAO acts and executes independently (not external or human-influenced) after triggers/decisions.
• DAO “hires” externals for operational work based on shareholders' decisions (no employees).
• Legal: Has a certain legal status or at least clear governance with regards to responsibilities and accountabilities.

Table 3
Mapping definitions and characteristics (green: a characteristic was mentioned or intended in the definition; orange: only partially matched; red: no matching).

Category	Funct.	Funct.	Gov	Gov	Gov	Gov	Gov	Gov	Gov	Gov	Tech	Tech	Tech	Other	Other	Other
Characteristic	(Conditional) storage and transfer of value	Notary function for decision-making	Decentralized on the infrastructure level	Decentralized on the application level	Autonomous decision-making	Organization and its cod are fully transparent	Stakeholders need to reach consensus for decisions by voting based on pre-determined voting rules	Updates, bugs, and optimizations need a democratic voting and decision-making by shareholders	Decision-making process always starts with a proposal or external trigger	Voting rights could be distributed either based on the amount of tokens owned or evenly	Smart contract-based (coded)	Code is open source	Is (public) blockchain based	Operational—autonomous execution of decisions	DAO "hires" external for operational work	Legal—certain legal status or clear governance with regards to responsibilities and accountabilities
Definition																
DAOs as entities that are decentralized and by the use of blockchain run autonomously and decentralized. Decision making is done by coded logic through the use of smart contracts. Decision-making is automated, this creates value for their customers. (Kypriotaki et al. [53])	2	1	2	1	2	0	0	0	0	0	2	0	2	1	0	0
Organizations that organize themselves through a democratic process on a public peer-to-peer and cryptographically secured network (not necessarily mention blockchain or smart contracts). Routine tasks, relying on voluntary contribution from the stakeholders of that DAO for all stages of the lifecycle (operate, manage and evolve). Code is open source. (Hsieh et al. [16], following Dietz et al. [55] and Van Valkenburgh et al. [56])	0	1	2	2	0	1	1	2	0	0	0	2	1	0	1	0
DAO is a new form of organization. Run on a public blockchain. Governance roles are encoded in smart contracts. Creating new forms of social interaction and order. (Dupont [28])	0	0	2	0	0	1	0	0	0	0	2	0	2	0	0	0
Decentralized way. Operations are controlled by pre-defined rules. A DAO is immune from attacks, both internally and externally and much more robust as result of reduction of human processes.	0	0	2	2	1	0	1	1	1	0	0	0	2	1	0	0
DAO as distributed autonomous organization. Can replace functions like voting andvarious forms of transfer of value by blockchain based code and execution. (Zachariadis, et al. [47])	2	2	2	1	0	0	0	0	0	0	1	0	2	1	0	0
An organization based on smart contracts on blockchain. Management and operational rules are coded. Can operate autonomously without central control or intervention possibilities. Challenge current hierarchical models, should lead to efficiency gain on various points like collaboration, decision-making and communication. (Wang et al. [18])	0	0	2	0	1	0	0	0	0	0	2	0	2	1	0	0
A DAO is blockchain based, using self-executing rules on a public blockchain. No central control, governance is decentralized. Enable people to self-govern and coordinate themselves. Decentralized and autonomous are still very much debated what is exactly meant by these term. (Hassan and De Filippi [19])	0	1	2	2	1	0	1	0	1	1	1	0	2	1	0	0
The definition of DAOs is subject to much debate as is the legal status. Debate around ownership and if they need to be operated by humans or human created entities or that they are autonomous, run completely by code. Answers to those questions depend on various circumstances. Set up to automate governance decision-making. Functionality is around storing and transferring value and has basically no other functions. If other functions need to be done, a contractor needs to be put in place. After approval by the DAO members, based on their respective token amount they hold, value can be transferred. Code is run via smart contracts on the Ethereum blockchain. (Jentzsch [12])	2	1	2	1	1	0	2	0	1	2	2	0	2	1	2	2
DAOs create of true sovereignty and change governance relationship by moving towards an opt in environment that the participant is both in control and is executing for others which is possible due to decentralized technologies without the need of a third party. (Aragon [60])	0	1	2	1	0	0	1	0	0	0	0	0	1	0	0	0
Honigman [61] described a DAO by dissecting the words. The DAO is autonomous as a result of self enforcing, programmes operating rules, running on a public permissionless blockchain where value can be immediately transferred and rules enforced as result of a decision. Decentralized can be understood in two ways. First as result of running on a blockchain and the second the lack of hierarchical organization with executives and shareholders. To organization can be an entity or something bugger like an organism of system.	2	0	2	2	1	0	0	0	0	0	1	0	2	2	0	1
A decentralized, transparent, and secure system for operation and governance among independent participants which "can run autonomously". (Beck [20])	0	1	1	1	1	2	1	0	0	1	0	0	0	1	0	0
DAOs are technically and governance wise much like conditional transaction applications, build in single or series of smart contracts, operating, once deployed, exactly as programmed in the business rules of the smart contracts. Possibilities for interference by humans in theory little to non and no formal company structure is behind it. (Rikken et al. [11])	0	0	1	1	1	0	0	0	0	0	2	0	1	2	0	1
Collective owner and managed organizations, using blockchain based smart contracts for coded rules. Members can propose and vote on any corporate type of decision. (Bellavitis et al. [58])	1	2	2	2	1	0	2	0	1	1	2	0	2	0	0	0

function of a DAO, supporting decision-making, is mentioned more often, directly or indirectly, than the transfer of value (which is the most common use case in practice). Also interesting is the fact that open source is hardly mentioned in the various definitions.

Based on the most commonly mentioned characteristics in the various existing definitions coupled with the observed characteristics that are present in almost all DAOs, we propose the following comprehensive definition of a DAO:

"A DAO is 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".

The definition implies that, on the infrastructure level, data and actions are recorded and autonomously executed by smart contracts and/or a blockchain protocol. At the application level, decisions cannot be made by a single participant but only by multiple participants utilizing various voting and governance mechanisms (reflecting the 'decentralization' component of DAOs).

The transfer of value can be interpreted in a broad manner. This can be in the form of the transfer of cryptocurrencies held by a particular DAO to a predetermined address, assigning voting rights to a certain address, or granting access to a system. Nevertheless, to address the first research question in this paper, we tried to find a definition that is not too broad or too narrow.

A common discussion regarding DAOs is about what decentralized and autonomous characteristics mean. According to Hassan and De Filippi in 2021 [19], "decentralized" can be viewed from the idea that DAOs are built on (public permissionless) blockchains. Hence, decentralization stems from the inherent properties of the blockchain. They also concluded that no study had yet examined the minimum size of DAO participants (i.e., tokenholders) involved in a DAO. Ramachandran and Qureshi [64] argued that DAOs are not decentralized, as small groups can issue changes, which is also witnessed in blockchain protocols that ought to be fully decentralized. [65]. Although not based on empirical data, the number of 20 participants was estimated as a minimum size [66]. Therefore, in the next section, we further empirically examined the significance of this decentralization level in terms of the number of participants.

4. DAO empirical analysis

The second research question is related to the ambiguity of the exact meaning of decentralization at the application level in DAOs, as described above in Section 3.4.1. Therefore, we analyze whether more tokenholders (thus, a higher level of decentralization) have an effect on the survival rate of DAOs (i.e., activity level). For the empirical analysis, we identified the total number of active DAOs, analyzed their characteristics and emerging developments, and gathered data on the individual DAOs to be used for statistical analysis.

The data were collected via (1) etherscan.org, an Ethereum blockchain browser; (2) apiary.1hive.org, where all deployed Aragon DAOs were displayed; (3) daohaus.club, where all deployed Moloch-based DAOs were displayed; (4) alchemy.daostack.io, where all DAOStack DAOs were displayed; and (5) various direct links to the self-built and blockchain-protocol DAOs that were found through extensive Internet research and Google Alert Services. For each DAO, all individual links were recorded. For every identified DAO, the specific data of this DAO were captured, i.e., age, number of tokenholders, number of activities in the form of public voting, type of DAO from a deployment perspective, and the protocol it was built on by looking at the on-chain data (monitored through the dedicated websites). If the information on the dedicated websites was inconclusive, the blockchain browser etherscan.org was used to look directly into the on-chain data of the smart contract addresses related to the DAO. This observation of activities was performed for a second time to observe changes in activities over time, with at least six months between the first and second analyses.

When looking at the absolute numbers of self-proclaimed DAOs, there has been a clear rise in the number of DAOs over the past years (see Fig. 1 in Section 1). We identified 1,859 potential DAOs, of which 1,635 seemed to be active, with traceable action via blockchain browsers and often individual reachable webpages per DAO. The analyzed number of 1,635 DAOs existing in this period is in line with other research [27]. The other 224 are in various stages of development, but no deployment activity was observed.

Fig. 5 shows two interesting events. The first is in Q4 2018, with a steep increase in the number of DAOs. This can be attributed to Aragon's launch, which was in October/November 2018. This marks the era of the parameterized DAO. The second rise is in Q4 2019, caused by a new rise of Aragon-based DAOs combined with the launch of Moloch/DAOHaus in Q4 2019. We will analyze the emerging trend further in Section 5. The 1,859 analyzed DAOs do not include all the perceived DAOs that use Snapshot by Snapshot Labs, which only emerged as of mid-2020 [67]. These DAOs were not analyzed in detail but only counted in absolute numbers, as they only emerged as of August 2020; hence, there was insufficient time to make a second measurement of the activity level. These perceived DAOs and the continued growth of DAOs post-August 2020 will be discussed later in Section 5 (the overview of emerging developments).

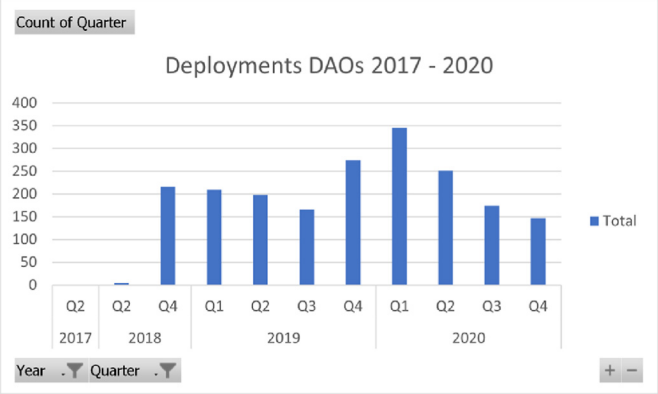


Fig. 5. Number of perceived DAOs per quarter (2017–2020).

When analyzing the DAOs based on deployment types or platforms, there were clear preferences and preferred blockchain infrastructure protocols. The distribution is shown in Table 4. Of the 1,635 active DAOs, the platforms or parameterized DAOs form the vast majority, with Aragon being the largest platform to create DAOs, deploying 1,497 of the 1,635 observed active DAOs.

Although Colony mentioned that their platform can be used for creating DAOs, we did not find any active DAOs on this platform. Similar results were found by El Faqir et al. [27]. Furthermore, the ability to launch a DAO was disabled at the time of writing this paper.

When analyzing preferred blockchain infrastructure protocols, with the dominant DAO platforms Aragon, Moloch, and DAOHaus, Ethereum is the protocol deploying the most DAOs (1,620). After Ethereum, the subsequent protocols on which DAOs were created during the analysis period are xDAI (currently Gnosis Chain, six DAOs in total, all DAOStack-based) and EOS (three DAOs in total, of which two were created with EOSDAC). At the time of writing, other protocols, such as Tezos (Homebase), Solana (Grape Network), Binance Smart Chain (xDAO), Polygon (Aragon Client), and Polkadot (Idavol and Spanner Protocol), were implementing DAO-deployment platforms. However, instantiation was not yet possible at the time of the initial data gathering (until June 2020).

The identified 1,635 active DAOs were analyzed for activity levels multiple times during the time period December 2019 until March 2021 to monitor changes in activities due to voting proposals, transfers of value, or changes in tokenholders over time.

Table 4
Division of DAOs by deployment type—platform.

Deployment type	Number of deployments until August 2020
Aragon	1,497
Moloch	84
DAOStack	39
Self-built	8
Blockchain	5
EOSDAC	2

4.1. Empirical classification analysis of DAOs

Previous research has primarily focused on the potential or possible setup of DAOs and mentioned only several individual DAOs without further in-depth empirical research. Only one study [27] conducted an analysis of the estimated number of DAOs deployed. However, this study by El Faqir et al. merely presented an aggregated overview analysis of the activities of the DAOStack-based DAOs and detailed the activity of one case, Genesis Alpha DAO. Their motivation is that this DAO represented 53% of the whole DAO stack activity. They did not include data analysis of other DAO platforms, blockchain-protocol DAOs, or self-built DAOs. They acknowledged that their analysis needs further investigation in empirical research. Our paper addresses their call.

Hence, our study monitored the activity of all 1,635 DAOs. Over the monitored period of time, the number of DAOs rose dramatically, especially as of Q4 2018. However, when monitoring the true activity of the DAOs, one can see in Table 5 that only 7.5% or 124 DAOs showed activity in the last six months of the monitoring period. There were 1,337 DAOs that did not show any recent activity. For five DAOs, we could not measure the activity level as the activity could not synchronize on their webpages despite various attempts. When monitoring activity over the whole monitoring period of 15 months, the activity level was 17.9%, or 293 DAOs.

When analyzing the DAOs that showed activity during the monitored period more closely, only 6% showed a high activity level, meaning that more than 10 transactions were performed during this period. The rest showed medium (2–10 transactions) activity (7%) or a low (one transaction) level of activity (5%). The threshold of 10 transactions for high activity was chosen because this, on average, comes to approximately at least one transaction a month for high activity during their active lifetime.

The analysis presented in Table 5 shows that blockchain protocol DAOs and self-built DAOs show significantly higher activity levels. The most commonly used platform in terms of absolute DAO numbers, Aragon, has a significantly lower activity percentage than all the other DAOs. Likely, this is because these DAOs might have been created for experimentation only when Aragon was the first platform to offer the creation of parameterized DAOs.

Next, we analyzed the average number of tokenholders in the various DAOs to analyze whether there was a relationship between the number of tokenholders and the activity level (Table 6). Within the Aragon and Moloch platforms, we found a clear relationship between the average number of tokenholders and activity level, i.e., the higher the activity level, the higher the average number of tokenholders. We further decided to perform a survivability analysis based on the activity level over time and the number of tokenholders.

4.2. Minimum decentralization in DAOs

An ongoing discussion with DAOs is whether the word ‘decentralized’ refers to the level of decentralization within a DAO itself or as the result of being built on a blockchain infrastructure [14]. When analyzing decentralization at the application level, we did so by analyzing the number of tokenholders in a DAO. Although the existing definitions directly mention decentralization at the application level or indirectly through the lack of central control, no minimum number was mentioned in any scientific articles. Only one blog by Rachmany [66] mentioned that a DAO below 20 participants does not make sense. This opinion was not further substantiated with arguments or empirical evidence. An argument is that the low level of decentralization could imply that the term DAO is used for marketing only or that it has centralized power as a community [68]. With our data, we empirically tested the level of decentralization by analyzing the number of tokenholders in relation to long-term viability.

To check this minimum number of tokenholders in DAOs in relation to the activity level, we analyzed the number of DAOs that showed no voting activity and compared these with the number of DAOs that did show activity since their deployment. As in this total of 1,635 DAOs, many DAOs were set up for initial experimental purposes only; therefore, our analysis focused on a particular subset, i.e., only the DAOs that showed high activity over their lifetime. Within this subset of DAOs, there is a group of DAOs that still showed activity until the date of the research and a group that had shown no more activity over the past 6–15 months during our research. The results show that there were no DAOs with more than 20 tokenholders that showed no voting activity. As shown in Table 7, all 683 DAOs without voting activity had 20 or fewer tokenholders. All of the active DAOs with more than 20 tokenholders showed activity. This confirms the expectation of Rachmany [66], suggesting that an active DAO should have at least 20 tokenholders.

To further examine whether the results based on Table 7 are robust, we performed a survival analysis through an ROC curve on the number of tokenholders and survivability in the form of both lifetime activity and current activity (Fig. 6). To do so, we only selected the DAOs with high lifetime activity to filter out as many DAOs as possible that were put up as

Table 6
Average tokenholders per DAO per activity level (December 2019–March 2021).

	High (10+tx)	Medium (2–10 tx)	Low (1 tx)	None
Aragon	21+	5.4	3.8	2.8
DAOStack	115	14.7 (3 DAOs, high 26, low 8)	1,645 (3 DAOs, high 4946, low 0 tokenholders)	18.3
Moloch	42	21	12	1.8
Blockchain protocol	1000+ (3 DAOs)	n/a	n/a	n/a
Self-coded	1000+ (5 DAOs, high 1000+, low 55, 1 n/a)	n/a	n/a	227 (1 DAO)
EOSDAC	n/a	n/a	n/a	n/a

Table 5
Activity level of DAOs (December 2019–March 2021).

	High (10+tx)	Medium (2–10 tx)	Low (1 tx)	None	Not measurable	Count of DAOs	Active in the last six months (till March 2021)	
Aragon	4%	7%	5%	84%	2	1,497	84	6%
DAOStack	26%	8%	8%	59%	0	39	9	23%
Moloch	13%	14%	7%	65%	0	84	21	25%
Blockchain protocol	60%	0%	0%	0%	2	5	3	60%
Self-coded	75%	13%	0%	0%	1	8	7	88%
EOSDAC	0%	0%	0%	100%	0	2	0	0%
Count of DAOs	91	114	88	1,337	5	1,635		
Active in the last six months (till March 2021)	69	37	24	0			124	
	69%	32%	28%	0%				

Table 7
Tokenholders per lifetime activity level.

	High	Medium	Low	None	Unknown	Totals
0 to 5	102	431	227	650	1	1411
6 to 10	32	29	6	6	0	73
11 to 20	22	11	3	8	1	45
21 to 50	21	4	0	0	0	25
51 to 250	27	1	1	0	0	29
250 plus	11	2	1	0	0	14
n/a	5	7	4	19	3	38
Totals	220	485	242	683	5	1,635

tests or play-arounds only, resulting in the analysis of 220 DAOs. For the analyses, the ROC curve is created with two variables: survival (coded as 1 in our data) and the number of tokenholders, with the following codes:

- Code 1: 0–5 tokenholders;
- Code 2: 6–10 tokenholders;
- Code 3: 11–20 tokenholders;
- Code 4: 21–50 tokenholders;
- Code 5: 51–250 tokenholders;
- Code 6: 250+ tokenholders.

As shown in Fig. 6, the cut-off point from the graph is approximately at the coordinate 0.279 (sensitivity) and 0.077 (1-specificity), which refers to Code 4 and Code 5 (i.e., above 20 tokenholders). This indicates that DAOs with at least 20 tokenholders have a higher chance of survival, which confirms the previous analysis.

An important note in this analysis is that the number of tokenholders is based on absolute numbers. No distinction was made between the differences in the voting power of the individual tokenholders, various governance models, or other possible factors that could influence the survivability of a DAO. The assumption underlying the analysis is that the number of tokenholders is equal to the number of accounts holding tokens. It is possible that a person or organization has multiple accounts and thus represents multiple tokenholders in a DAO. In their research on voting power distribution, Fritsch et al. also described the challenge of address clustering [33], meaning that a person could use multiple accounts containing governance tokens. The effect of voting power distribution among tokenholders and address clustering separately and in relation to the survivability of DAOs should be investigated in further research.

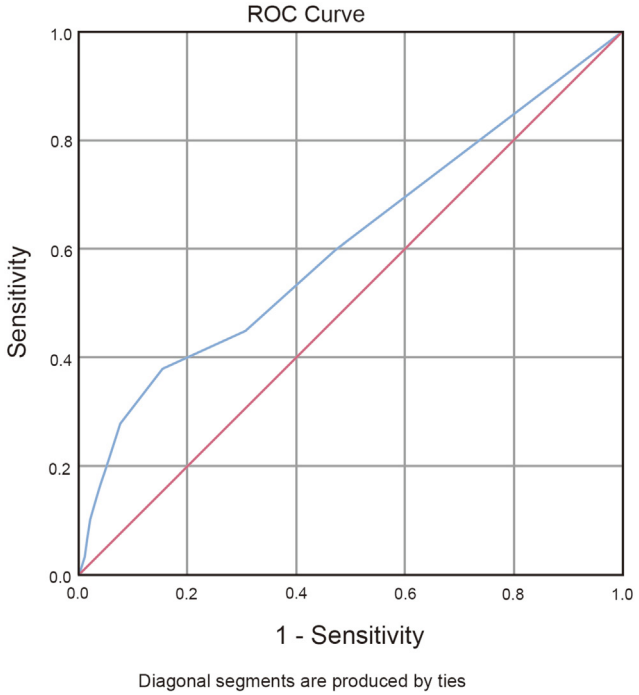
Furthermore, we took activity level as the denominator for survival. Due to the business purpose of a DAO, low activity is to be expected. Therefore, the purpose or goal of a DAO in relation to its activity level should also be investigated in future research. Adding the business purpose will also help filter out possible test or play-around DAOs that could distort the outcome.

Finally, DAOs using off-chain governance mechanisms, like Snapshot, were not included in this dataset, as these DAOs were not yet available during the whole initial measuring period. Also, as a result of the analyzed dataset containing many early deployed DAOs, due to few alternatives available, there could be a bias towards certain deployment platforms like Aragon, DAOHaus (Moloch), and DAOStack. New deployment platforms that might contain new functionality, new user interfaces, and user friendliness might influence the relationship between decentralization and long-term viability.

5. Emerging developments

Our final research question investigates emerging developments that could influence the definition of DAOs in the future or could challenge or even disqualify many perceived DAOs due to their changing characteristics. For this, we analyzed, in addition to the 1,859 potential DAOs used in research questions 1 and 2, an additional 8,000+ DAOs that were created in the period from mid-2020 until October 2021. After excluding DAOs without activity and specific (active) websites with information on the DAO, a total of 9,845 DAOs were used for identifying and analyzing emerging developments, e.g., (1) the trend to self-coded smart contracts or protocol-based DAOs; (2) parameterized platform DAOs; and (3) off-chain voting.

First, our empirical data show that since the creation of the first DAO in 2014, most of the DAOs created in the beginning were blockchain-based DAOs, thereafter closely followed by coded or smart contract-based DAOs. These DAOs were all unique in their code, not making use of templates, as shown in Fig. 7 below.



Coordinates of the Curve

Test Result Variable(s) Token holders category

Positive if Greater Than or Equal To[a]	Sensitivity	1 - Specificity
.00	1.000	1.000
1.50	.589	.462
2.50	.450	.308
3.50	.380	.154
4.50	.279	.077
5.50	.109	.022
6.50	.031	.011
7.50	.000	.000

The test result variable(s): Token holders category has at least one tie between the positive actual state group and the negative actualstate group.

a. The smallest cutoff value is the minimum observed test value minus 1, and the largest cutoff value is the maximum observed test value plus 1. Allthe other cutoff values are the averages of two consecutive ordered observed test values.

Fig. 6. ROC curve (with coordinates) to examine the number of tokenholders and DAO survivability.

Second, in 2018, after the initial rise of the deployment of manually coded DAOs and blockchain DAOs, the parameterized platform DAOs arose. These DAOs no longer need manual coding but can be created by filling in parameters on a website. These parameters correspond with a standard smart contract template's variables, which are then deployed on the blockchain in the background once all parameters are filled in and checked. The majority of active DAOs are currently created through these platforms. As shown in Fig. 5, a clear and sudden increase in DAOs occurred in Q4 2018. This rise resulted from Aragon's launch, offering the first parameterized DAO creation platform. Fig. 5 also shows clear growth in Q4 2019 as a result of the launch of the DAOHaus parameterized DAO creation platform for Moloch-template DAOs. Although Aragon-based DAOs still remain the largest DAO platform-created DAOs in total numbers, as of 2021, the Moloch-based parameterized DAOs created on DAOHaus took over, with DAOHaus becoming the dominant DAO platform for creating new DAOs, as shown in Fig. 8.

Also, during the rise of the platform DAOs, the number of choices regarding governance types (decision-making within DAOs) increased over the past years, e.g., Aragon added company, membership, and reputation in September 2019. However, many of these are still theoretical models [54,64,69–71], as most of the new governance types are not yet integrated with the templates of the parameterized DAO creation platforms.

Third, the most recent development that we analyzed is off-chain voting. Traditionally, DAOs recorded all voting and transactions and execution thereof on a blockchain (so-called on-chain systems). There is a clear development in off-chain voting. This seems to be a direct result of the increasing "gas" prices (gas refers to the transaction costs for running smart contract code on Ethereum), making voting and usage of DAOs in practice more expensive. Through Snapshot, Boardroom, and Aragon Govern mechanisms, off-chain voting is possible for Ethereum and Ethereum-based blockchain protocols like xDAI, Binance Smart Chain, and Ethereum testnets [72,73]. This means that the vote itself is not recorded on the blockchain directly but is based on token balances that the tokenholders had at the "snapshot" of the proposal. At the time of writing (mid-2022), the number of DAO projects registered on Snapshot exceeded 6,500, which is a rapid increase considering that Snapshot only surfaced around August 2020 [67]. Fig. 9 shows the blockchain-based DAOs complemented by the emerging developments of specific hard-coded smart contract DAOs, platform-parameterized DAOs, and off-chain voting DAOs over time.

Despite the benefit of using Snapshot (no need for gas as voting occurs off-chain; thus, no transaction fees need to be paid to cast a vote), the downside is that the voting outcome is not executed directly. Direct execution is not possible because Snapshot needs additional tooling to automate the execution of the voting, as the voting in itself on Snapshot is not binding [74]. This development could lead to lower entry barriers for using DAOs due to the lower cost of governance. However, this simultaneously poses the challenge of a higher level of centralization or censorship, as there is no guarantee that the outcome of the vote is being executed. Hence, this creates a dependency on the actors that are able to execute the vote at the expense of autonomy.

Besides in Snapshot, the separation of execution and decision and not integrating them into the smart contract structure are also used in Boardroom DAO and Tally platforms. The difference is that within the last platform, multiple governance structures can be applied [69]. These platforms often make use of Snapshot in the back-end with just a Tally or Boardroom front-end.

In sum, aside from the benefits, we highlight two critical points of attention: (1) there is an increased centralization risk, and (2) this also challenges the autonomy of a DAO. First, the increased risks of centralization refer to the fact that after a decision is made, a small group (or even a single person) needs to follow up on the transaction, creating a potential single point of failure in the process. Second, as voting decisions are made off-chain using platforms like Snapshot, the voting results will no longer be automatically executed. Thus, since autonomous execution

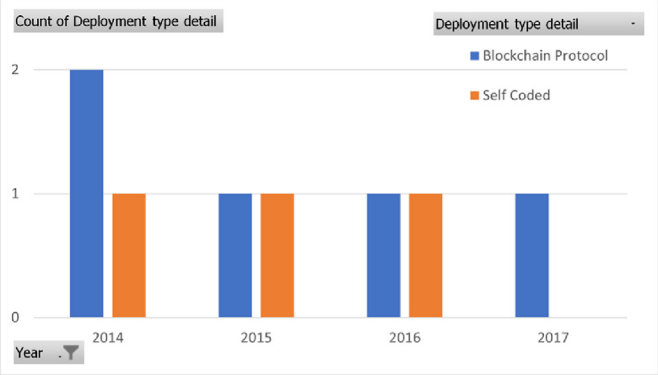


Fig. 7. Deployment type of DAOs (early trends during 2014–2017).

is removed, initiatives that use these types of constructions no longer need to adhere to the definition of DAOs. Therefore, rather than DAOs, these types of initiatives embody decentralized organizations in which processes are manually (instead of automatically) executed. Moreover, it seems that this autonomous issue became a real risk when the Tribe/Fei DAO incident occurred in mid-2022, in which a decision made via Snapshot was not executed according to the outcome of the decision [75,76]. The incident clearly shows the lack of autonomy in these off-chain governance DAOs.

Hence, since off-chain governance comes at the cost of autonomy, DAOs no longer adhere to our proposed unified DAO definition. This implies that many perceived DAOs may lose their autonomy, causing them to be disqualified as DAOs per definition. Despite the perceived exponential growth in Fig. 1, following our definition, this may actually lead to the number of DAOs declining in the annual growth percentage in 2021. We suggest not using the term DAO for these kinds of applications, as the autonomous and decentralized characteristics are violated, and instead using the term Decentralized Organizations (DOs) or Decentralized Partially Autonomous Organizations (DPAOs). Although autonomous execution might be challenged, the intention is still to organize the organization in a decentralized manner.

6. Conclusions and recommendations

There has been a clear rise in the number of DAOs over the last few years. This rise in the number of DAOs is marked by the release of DAO creation platforms like Aragon, Moloch DAO, and DAOStack. Although there are an increasing number of DAO creation platforms, Aragon remains dominant. Regarding the infrastructure used, multiple platforms can be used to create DAOs. Ethereum is the dominant platform so far.

The analysis of the empirical data shows a link between the number of tokenholders and the survival rate of DAOs. Our empirical result corroborates the previously mentioned number of 20 tokens by Rachmany [66]. The survivability analysis shows that DAOs with a larger number of tokenholders have significantly longer survivability than those with a lower number of tokenholders. Our analysis shows that the number of 20 tokenholders is the tipping point. Furthermore, this number can be viewed as an indicator of the level of decentralization at the application level of DAOs. It can be an important factor in preventing centralized power and possible censorship by small groups within the DAO. A limitation of our analysis is that we only took into account the absolute number of tokenholders in the form of different account addresses. Hence, we have not yet incorporated relative voting power or the possibility of one person or an institution being in control over multiple addresses. We recommend this for future research. Furthermore, we analyzed the relationship between tokenholders and survivability based on activity levels only. As the business objective of a DAO could very well affect activity levels, the purpose of a DAO should also be taken into account in further research.

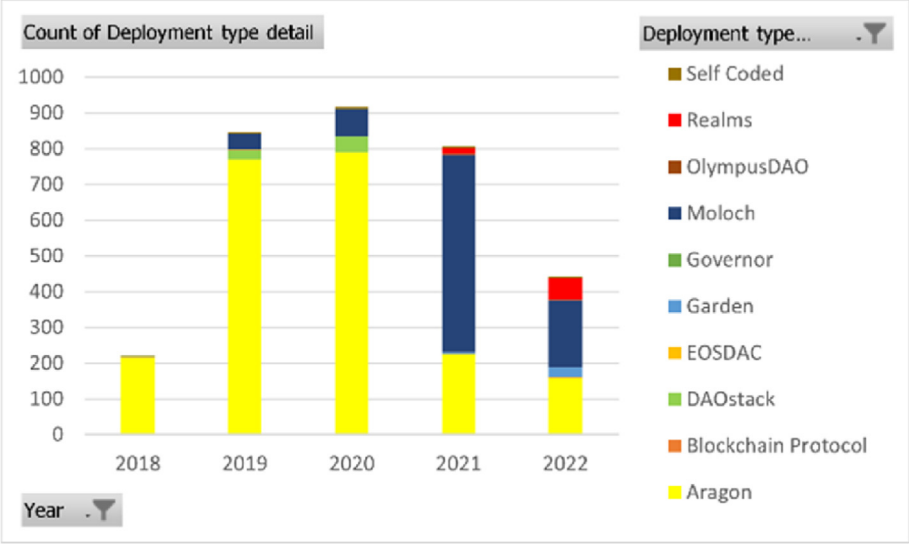


Fig. 8. Division of deployment platform types of DAOs from 2018 to mid-2022 (numbers of self-coded, blockchain protocol, governor, OlympusDAO, and EOSDAC DAOs are extremely small and not well visible in the diagram).

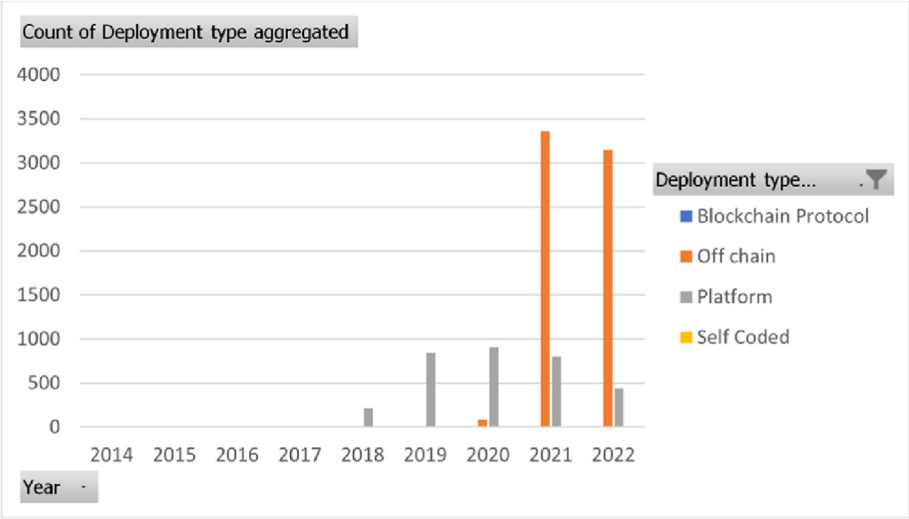


Fig. 9. Emerging developments in DAOs (from 2014 to mid-2022).

Although many DAO definitions exist, there is no agreement on what constitutes a DAO. There are various characteristics that the different definitions have in common. Based on the analysis of definitions and by analyzing the common characteristics in these definitions, we derived the essences of DAOs and proposed the following unified definition of DAOs:

"A DAO is 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".

The definition implies that, on the infrastructure level, data and actions are recorded on and autonomously executed by smart contracts and/or a blockchain protocol. It also implies that at the application level, decisions are never made by a single tokenholder but always by multiple tokenholders utilizing various voting and governance mechanisms.

New technology developments challenge the 'autonomous' part of DAOs. Off-chain initiatives that separate the decision-making from the execution of decisions make DAOs less autonomous and run the risk of becoming centralized. This is because the follow-up actions must be triggered manually and are no longer automatically executed based on the decision outcome. These types of initiatives can be better classified as decentralized organizations (DOs) or Decentralized Partially Autonomous Organizations (DPAOs) instead of DAOs.

Although our definition will indeed exclude many of the projects that call themselves DAOs, we do believe that this definition helps provide a clear distinction between real DAOs and perceived (self-proclaimed) DAOs. For instance, DAO projects using Snapshot or Scattershot do not, by the same standards as real DAOs, autonomously execute decisions through smart contract execution on-chain directly triggered by that decision but require an intermediate, often manual, and off-chain action.

For future research, we also recommend the following four key research directions. The first one relates to many of the DAOs analyzed, consisting of early deployed DAOs at an early (experimental) stage and/or experiments, and the numbers are rising rapidly. Thus, the dataset could be biased toward earlier DAO deployment platforms like Aragon. Although the size of the subset of analyzed DAOs on survivability rate in relation to the number of tokenholders in this research was over 200 DAOs, we recommend repeating this analysis with a larger set of data with a longer lifetime to draw a more robust conclusion, including more recent and upcoming platforms. Also, we divided the number of tokenholders into categories (categorical scale instead of a ratio scale in our

analysis). We recommend that with a larger dataset, the analysis should also be performed at the ratio scale of the tokenholders. Secondly, besides the absolute number of tokenholders, research should be conducted on other possible drivers that can potentially influence activity and survivability, like governance, voting power distribution and address clustering, voting mechanisms, and the business objective of a DAO. Thirdly, a classification of perceived DAOs that are closer to DOs or DPAOs could be set up, as this seems to be the organization emerging after DAOs. Finally, a deeper understanding of the off-chain voting DAO trend is needed in further empirical research in which the true level of decentralization in these DAOs or DPAOs should be investigated, as well as the number of tokenholders that can execute a voting or decision and the survivability rate. In this way, these DAOs or DPAOs can be compared to the DAOs where voting and execution are recorded and performed on-chain.

Authorship contribution

Olivier Rikken: Formal analysis, Writing—original draft. **Marijn Janssen:** Formal analysis, Writing—original draft. **Zenlin Kwee:** Formal analysis, Writing—original draft.

Declaration of competing interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests. Olivier Rikken reports a relationship with Central Bank of Curaçao and St. Maarten that includes: speaking and lecture fees and travel reimbursement. Olivier Rikken reports a relationship with Nyenrode Business University that includes: speaking and lecture fees. Olivier Rikken reports a relationship with Smart City OU—CryptoFin Conference that includes: speaking and lecture fees and travel reimbursement. Olivier Rikken is active as consultant in the blockchain community on various blockchain related topics, but has no financial interest or participation in any DAO at the time of writing.

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