



Blockchain and the emergence of Decentralized Autonomous Organizations (DAOs): An integrative model and research agenda

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ABSTRACT

Decentralized autonomous organizations (DAOs) are blockchain-based organizations fed by a peer-to-peer (P2P) network of contributors. Their management is decentralized without top executive teams and built on automated rules encoded in smart contracts, and their governance works autonomously based on a combination of on-chain and off-chain mechanisms that support community decision-making. A growing body of literature has emerged exploring DAOs. However, there is a considerable lack of clarity about this organizational design and its theoretical conceptualization. To this end, we undertake an integrative literature review that reveals three main principles—decentralized, automated and autonomous organizations—and the following four theoretical perspectives mainly adopted to examine this novel organizational form: transaction cost theory, institutions for collective action, agency theory, and socio-materiality. By extending these theories, we propose an integrative model of DAO for research and theory building. Our contribution provides conceptual clarity and proposes a framework for future research directions.

1. Introduction

When the first DAO (a venture capital organization) failed in June 2016, 18,000 cryptocurrency investors lost 11.5 million ethers (ETH), approximately \$50 million (Wang et al., 2019). The first DAO represented an experiment with a new organizational design known as “Decentralized Autonomous Organizations (DAOs)” (Buterin, 2014; DuPont, 2018; Hsieh et al., 2018), and the DAO was the first organization to adopt this generic name. The main goal of the first DAO founders (Buterin, 2014) was to create organizations that do not require managers and hierarchies; thus, they are substituted with automated tasks based on smart contract in the blockchain protocol. This first DAO was based on Ethereum, a smart contract code system built atop a blockchain platform and launched in July 2015 using the *ether* (ETH), the Ethereum cryptocurrency. Its goal was to create a digital, collaborative peer-to-peer (P2P) community of investors and entrepreneurs, building a crowdfunding network to further develop the Ethereum ecosystem with new organizations. The first DAO founders proposed that investors use ETH to create charity and commercial projects that should be voted upon by investors to be funded. Finally, although the failure of this first DAO stemmed from security code vulnerabilities affecting the novel

Ethereum smart contract code that managed the common pool of ETH, most of these issues have been resolved today (Wang et al., 2019).

As a result, since the failure of the first DAO, a large number of DAOs have emerged, such as DAOstack, DAOhaus, Moloch DAO, Uniswap, BitDAO, Mango DAO, Compound, Radicle, Maker DAO, Decentraland, and Aragon among others. In April 2022, there were approximately 220 DAOs according to Deepdao analytics.¹ Each DAO has a different goal. For example, *DAOstack* proposes a venture capital based on the Ethereum blockchain. *Democracy Earth* works for borderless democracy creating a public conversation regarding the internet as a planetary jurisdiction. Further, *Decentraland* is a metaverse platform that has developed a virtual world that is recorded on the Ethereum blockchain, on which contributors can build their own environments and communities. Finally, as an example of a single-purpose DAO, *ConstitutionDAO* joins a P2P community to get funding to purchase an original copy of the United States Constitution and finally bid \$43.2 million in the Sotheby's auction in November 2021. Table X (Appendix 1) illustrates some DAOs.

We define DAOs as *blockchain-based organizations fed by virtual open networks of contributors (investors in cryptocurrencies). Their governance and management are decentralized without central control and are built on*

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¹ <https://deepdao.io/organizations> (accessed 11.4.2022).

automated rules encoded in smart contracts stored and executed in blockchains. This structure enables peers to work *autonomously* based on a system of on-chain (machine consensus) and off-chain (voting rights) mechanisms of governance that support community decision-making and drive distributed trust among peers (Buterin, 2014; Wang et al., 2019). Further, the operationalization of DAOs is based on token economy principles: DAO functioning requires the development of a governance token based on cryptocurrency investment. DAO investors receive these tokens that allow ownership and governance. Token holders have voting rights in the community according to the share of their token holdings and use tokens to adopt DAOs internal activities (DuPont, 2019; Hsieh et al., 2018; Wang et al., 2019).

The emergence of DAOs is based on two broad underlying transformations: (1) the changes in digital platforms and decentralized organizations, and (2) the emergence of advanced information technologies that enable new sociomaterial entanglements.

DAOs emergence responds to a long-standing tradition of exploring decentralized organizations (Mintzberg, 1993). With the rise of the Internet, open-access communities and open-source software digital platforms have led to an important shift in experimenting with decentralization (O'Mahony and Lakhani, 2011). In the last few decades, digital platforms and open-access communities have adopted new information technologies for planning, modeling, and sharing resources and for launching new products, services, and business models (e.g., open-source software, P2P lending, crowdfunding, and apartment/house renting and sharing platforms) (Fjeldstad et al., 2012; O'Mahony and Ferraro, 2007). These digital platforms have transformed the way digital business organize and create value with contributors and customers (Von Hippel and Von Krogh, 2003) while collaboratively working and exchanging resources in the digital space (Bailey et al., 2012). However, they still rely on central management and hierarchies to control decision-making and economic performance and benefits (De Filippi, 2017).

By contrast, blockchains have introduced new technologies that serve to decentralize management and avoid third-party supervision, using distributed ledgers to generate a set of chains using machine consensus to verify and validate transactions and information exchange records, as is the case with cryptocurrencies and supporting automated tasks in smart contracts (De Filippi, 2017; Wang et al., 2019). In doing so, the development of blockchain technologies has enabled the creation of DAOs that allow people around the world to cooperate on real-time projects and create value for all using cryptocurrencies and tokens as investment assets and pools of shared resources (Van Rijmenam, 2019).

The second main underlying concept is the current transformation of the constitutive entanglement of the social and the material in organizational life (Orlikowski, 2007) and "conjoined agency" (Murray et al., 2021a) between humans and machines, supported by advanced information technologies, such as blockchain, Big Data, and artificial intelligence. Over the last few decades, scholars have examined how emerging information technologies have transformed organizational practices and interactions (Orlikowski, 2007; Von Hippel and Von Krogh, 2003; Bailey et al., 2012). These technologies challenge the way humans build organizations (Seidel, 2018; Von Krogh, 2018) in the age of learning algorithms (Faraj et al., 2018). These changes are based on technological affordances, substituting human actions with machine-automated orders (Zammuto et al., 2007) and replacing human-to-human interactions with human-to-machine interactions (Van Rijmenam, 2019). In this article, DAOs are viewed as the entanglement between the social (human) and material (technology) (Orlikowski and Scott, 2008).

The development of DAOs has attracted the attention of researchers across multiple fields of research who want to understand this novel organizational design and its implications for technology, society, business, politics, and the economy (Atzori, 2017; Berg et al., 2019; De Filippi and Hassan, 2021; DuPont, 2018, 2019; Hsieh et al., 2018, 2018a; Vergne, 2020; Wang et al., 2019). The literature shows how

DAOs elicit multifaceted and interdisciplinary inquiries. However, the existing literature barely addresses DAOs' conceptualization and underlying theory building, and the majority of previous articles primarily focus on the overall conceptualization of blockchain technologies. Recent research has called for a shared conceptual approach to understanding DAOs and exploring future theory building (Hsieh et al., 2018; Seidel, 2018; Wang et al., 2019). In particular, a conceptual framework is needed to clarify the main theories and define future research directions.

To address this gap, we conduct an integrative literature review (Torraco, 2005), adopting systematic string-based database searches and cross-reference snowballing. We first explore the underlying principles of DAOs and their performance and operationalization. Our research revealed a set of research gaps and four main theoretical views applied to DAOs in the literature: transaction cost, collective action, agency, and sociomateriality theories. Consequently, we explore the integration of these four theoretical perspectives, aiming for interdisciplinary theoretical development, exploring how to cope with the research gaps and propose future directions for research.

The remainder of this paper is structured as follows: Section 2 describes the research methodology based on an integrative literature review with the goal of critically analyzing the literature and exploring the underlying theoretical research on DAOs. Section 3 presents the main outcomes of the critical analysis of the literature understanding three DAO organizational principles: decentralized, automated, and autonomous organizations, and Section 4 explores the main theoretical perspectives used to examine DAOs. As a result of the integrative literature review, Section 5 builds on both to present an integrative model of DAO for research and theory building and explores a research agenda. We conclude with some final remarks.

2. Research methodology

In this article, we propose an integrative literature review (Torraco, 2005) comprising two main stages. In the first stage, we critically analyzed the literature, deconstructing DAOs into basic components, research gaps and the scientific discussions on DAOs while exploring the underlying theoretical perspectives. In the second stage, we synthesized the literature to connect different components and build an integrative model of DAO and research agenda (Torraco, 2005).

We applied a four-step protocol. First, we systematically gathered relevant literature (Tranfield et al., 2003) and conducted a systematic database search, followed by cross-reference snowballing, as illustrated in Fig. 1. We reviewed literature published from 2010 to 2020, searching the Web-of-Science and Elsevier Scopus databases. The search strings included the following keywords: DAO/s, decentralized autonomous organizations, Bitcoin, blockchain, blockchain governance, DAO governance, and smart contracts in titles, abstracts, and keywords. Due to the nature of this emerging topic, we primarily included scientific articles published in peer-reviewed journals, but also some relevant conference proceedings, books, and concrete whitepapers and reports dedicated to DAOs. Following the first search, we analyzed the initial sample by scanning the publications' titles and abstracts, and the cited content in the texts, to determine whether the documents were relevant. We reiterated this process for novel relevant papers and books, carrying out a cross-reference search. We subsequently added important documents to our sample. We also employed snowballing techniques to add documents from blockchain and DAO communities. This iteration process continued until we found no more relevant references. In total, we retrieved 222 papers from the databases.

In the second step, our goal was to select publications that responded specifically to our research. We adopted two selection criteria: (1) a focus on DAOs, their organizational principles and performance, including their agency, governance, and entanglement with blockchain technological developments; and (2) conceptual and theoretical contributions to DAOs and blockchain. We carefully read all the abstracts,

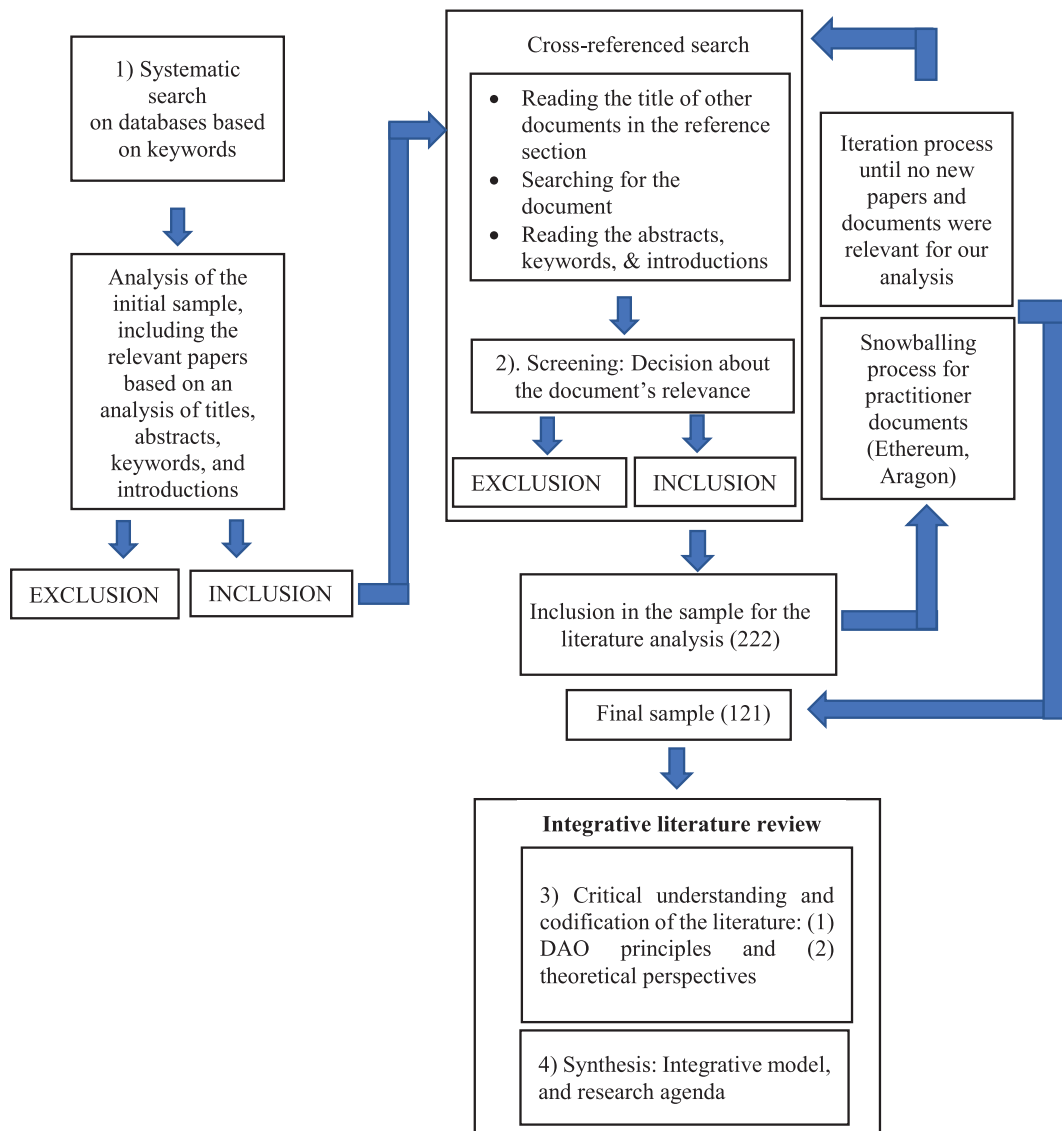


Fig. 1. Literature review approach, process, and outcomes.

introductions, and discussion sections of all the publications. The first author conducted the reading, analysis, and selection processes, while the second author validated the choices and documents and inductively coded articles using technological and organizational knowledge, as well as identifying constructs, theories, and research gaps. With this approach, we reduced our selection to 121 papers.

Third, we proceeded with an in-depth reading and critical understanding of the selected literature to understand DAOs according to scientific research, performance and theoretical perspectives. The data analysis included content analyses and coding techniques. The first author deconstructed DAO and blockchain literature based on their basic components, principles, and gaps, searching for consistencies and commonalities through the documents' codification. He categorized publications according to their main DAO principles, research streams and theoretical contributions. The second author validated these processes. Both authors analyzed the literature critically, examining the main definitions, principles, theories, and research gaps, as illustrated in [Tables 1 and 2](#). These results are presented in this article: (1) DAO principles and their performance and (2) theoretical perspectives.

The final step involved synthesizing our results with the theoretical conceptualization and analysis of the directions of future research. In this step, we built our integrative model of DAO for research proposing

avenues for theory building and developing a research agenda ([Torraco, 2005](#)). The next two sections describe the main outcomes of the integrative literature review.

3. DAOs

The first main outcome of the literature review is the analysis of the main principles that explain the performance of DAOs, which are defined as decentralized, autonomous and automated organizations ([Wang et al., 2019](#)). It is the integration of the three principles that explains the operability of DAOs as a new organizational design. [Table 1](#) illustrates the main definitions of DAOs in the literature.

We examine each principle and its performance, and we identify the main research gaps in the literature ([Table 2](#)).

3.1. Decentralized organizations: roles and tasks

DAOs enable digital joint self-organized communities to cooperate on shared goals without any formal management hierarchy, centralized control, or even third-party intervention and supervision ([Sigh and Kim, 2019](#)). In doing so, DAOs create a digital P2P community of contributors who adopt different roles and automated tasks that complete the

Table 1
DAO literature, selected definitions.

Authors and field of research	Definition of DAO
Atzori (2017, p. 54) Political Science	"In a hypothetical, fully decentralized society run through smart contracts, Decentralized Autonomous Organizations and market rules, individuals live in a kind of pre-sovereignty condition: on a case-by-case basis, they self-organize and cluster around common needs and interests, which they try to administrate or secure through consensus-based automatized procedures, accepted by the parties involved. For example, they may use decentralization platforms to manage distribution of resources, run reputation-based systems or organize any kind of services through crowdfunding."
Berg et al. (2019, p. 9) Economy	" Distributed autonomous organizations are organizations built around smart contracts and a blockchain controlled in a decentralized manner by its owners."
De Filippi and Hassan (2021, p. 2) Technology	"A DAO is a blockchain-based system that enables people to coordinate and govern themselves mediated by a set of self-executing rules deployed on a public blockchain, and whose governance is decentralized (i.e., independent from central control)."
De Filippi and Wright, 2018, p. 146. Technology and Legal Studies	"A DAO represents the most advanced state of automation, where a blockchain-based organization is run not by humans or group consensus, but rather entirely by smart contracts, algorithms, and deterministic code."
DuPont (2019, p. 193, p197, p. 199) Ethics and Information Systems	"Blockchain technologies promise not just new ways of doing business – they promise to overhaul how decisions are made, activities are coordinated, and relationships are formed. [...] Decentralized autonomous organizations are blockchain and smart contract systems for human and machine coordination and decision-making. DAOs rely on blockchain technologies to execute code and record transactions and use smart contracts to tie together people, information sources and algorithmic agents." "A DAO is any organization that is capable of running autonomously and has a decentralized (or really distributed organizational structure)." "DAOs are capable of supporting collective action and decision-making at a tremendous range of scales – from the smallest company to nation states. [...] DAOs can support bottom-up decision-making."
Hsieh et al. (2018, p. 2) Management and Organization Studies	"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. [...] DAOs coordinate routine tasks through cryptographic routines (as opposed to human routines)."
Sigh and Kim (2019, p. 115) Information Systems	"[A] Decentralized Autonomous Organization is [a] novel scalable, self-organizing coordination on the blockchain, controlled by smart contracts and its essential operations are automated agreeing to rules and principles assigned in code without human involvement."
Wang et al. (2019, p. 871) Information Systems and Technology	" DAO is a blockchain-powered organization that can run on its own without any central authority or management hierarchy. In a DAO, all the management and operational rules are recorded on blockchain in the form of smart contracts, and the distributed consensus protocols and Token Economy Incentive are utilized to realize organizations' self-operation, self-governance, and self-evolution."
Van Rijmenam (2019, p. 23) Technology, Management, Business	"The result is the emergence of new organizational designs, including that of a Decentralized Autonomous Organization (DAO), which uses the

Table 1 (continued)

Authors and field of research	Definition of DAO
Vergne (2020, p. 1) Management and Organizational Studies	blockchain and smart contracts to establish governance without management or employees, run completely by computer code." " Decentralized organization and distributed organization are often used interchangeably, despite describing two distinct phenomena. I propose distinguishing decentralization, as the dispersion of organizational communications, from distribution, as the dispersion of organizational decision-making. Organizations can be distributed without being decentralized (and vice versa), and having multiple management layers directly affects only distribution – not decentralization."

Table 2
DAO principles and research gaps.

DAO principles	Research gaps
Decentralization	<ul style="list-style-type: none"> Extended research on decentralization and lack of hierarchy in DAOs Lack of empirical analysis and field research on Borrar PP. Incluir: DAO communities Extended research on the complexity of DAOs' roles and contributors, and the emergence of new roles and automated tasks Lack of understand about how DAO perform, including hierarchies/ tensions in DAO communities Lack of understanding of power distribution and the impact of powerful contributors Extended research on the impacts of DAOs in democracy and the impact on a stateless global society Extended research on the impacts of DAOs to undermine the capacity of central governmental authorities to supervise economic, banking, commerce, and legal activities
Automated	<ul style="list-style-type: none"> Extended research on the limitation of smart contracts and code-is-law in DAOs internal regulation Exploring the future of DAO and blockchain technologies, e.g., incorporating AI, Big Data, or IoT Exploring the future impact of DAO on economic, commercial, and societal regulations Extended research on how DAOs' transform work or generate new work Extended research on understanding DAOs application in business and value creation
Autonomous	<ul style="list-style-type: none"> Exploring the entanglement between machine and human governance Extended research on DAO governance: the performance of off-chain mechanisms for community decision-making Novel research on DAO and token economics, rewards, and remuneration as a reputation system in DAOs Novel research on DAOs accountability and use for illegal activities Extended research on the impact of DAOs on ethics and democratic issues Extended research on DAO applications in business models

functions for the organization to work (De Filippi and Hassan, 2021). Thus, DAOs differ from hierarchical organizations because they do not have executive boards and CEOs who decide for everyone else; rather, the entire P2P community of contributors proposes, votes, and decides (Wang et al., 2019). DAOs also differ from digital open-access platforms in that software developers contribute as investors and propose DAOs. In DAOs, all members can participate on collective decision-making and investment decisions (Hsieh et al., 2018).

Although decentralization is the core principle of DAO, there is no universally accepted view of decentralized organizations in the literature. The focus of the analysis varies among different disciplines and authors. For example, some political scientists see DAOs as an important risk and drawback for the nation-state, public services, and democracy. Atzori (2017) argues that DAOs may lead to a general disempowerment of nation-states, as they lose control and supervision of traditional

mechanisms of state authority. There is a risk of undermining the capacity of central governmental authorities to supervise banking, commerce, and legal activities (De Filippi and Wright, 2018; DuPont, 2019). Further, DAOs can drive the emergence of a stateless global society transforming the mechanism of democratic voting and decision-making beyond the governmental boundaries; thus, Atzori (2017) advocates for the need to regulate decentralized governance and DAO. By contrast, new institutional economists, such as Berg et al. (2019), study DAO based on the emergence of a novel economic institution “cryptoeconomics.” They explored how this emerging institution might influence and transform the evolution of capitalism with novel norms of decentralization, distributed trust, and de-hierarchicalization of supervision and control. As a result, DAOs have become a main “ambitious application (to) exploit the possibilities of smart contracts to coordinate activity without the need for hierarchy and human agency” (Berg et al., 2019, p. 9). To bring further insights, information technologist, DuPont (2019, p. 193) sees DAOs as an organizational movement that could potentially be “the promise of new organizations” that attempt to solve collective action and decision-making problems. His argument is that DAOs can bring important corporate, societal, and political transformation based on bottom-up decision-making. However, the literature show how DAO experimentation still has important challenges, including security issues, governance issues about power distribution and hierarchies, and ethical dilemmas of implementation (Wang et al., 2019).

For example, emergent empirical analysis of existing DAOs reveals that they do not always involve real decentralized practices and lack of hierarchy; by contrast, DAOs are less rigid hierarchically than other organizations, though some actors, such as the founders or developers, have a powerful influence on the peer community (DuPont, 2019; Hsieh et al., 2018a, 2018b). This imbalance in power can generate tensions in DAOs, for example, with off-chain human or community governance and novel type of emerging hierarchies. As a result, further research is required on the issue of decentralization to examine the transformation of hierarchies, control, and the distribution of power in DAOs (Vergne, 2020).

3.1.1. Roles and tasks

Decentralization is based on a set of different roles and automated tasks adopted by the P2P community for validating, governance and decision-making. These automated tasks are based on DAO smart contract and are encoded in the blockchain protocol (Wang et al., 2019). DAOs also include other roles and tasks based on autonomous off-chain human interactions, mainly collective decision-making and voting (Hsieh et al., 2018). To understand how these decentralized organizations perform, we focus on the main roles and tasks of DAOs.

The **founders** are those who propose the DAO in a seminal document called a “DAO whitepaper.” In practice, DAOs are launched by a group of founders who present the original goals and rules to other cryptocurrency investors in a “whitepaper” that they publish on social media (DuPont, 2019). The founders' goal is essentially to disseminate the idea and attract new investors. The whitepaper provides investors with the main decentralized philosophy, concepts and purpose, together with technical, organizational, and investing information about the DAO roadmap. Typically, DAO whitepapers defend actions on certain challenges (e.g., venture capital, Earth democracy, metaverse) and propose how to solve these goals by cooperating through a decentralized organizational structure, generating a community of P2P network of contributors. Founders also open the source code of the blockchain and smart contract to promote software development collaboration with other developers interested in their DAO project (Arruñada and Garciano, 2018; Islam et al., 2019). In summary, DAO founders define governance and functioning rules, but machines apply them (DuPont, 2019).

The **investors** are cryptocurrency holders that invest in DAOs and become members. When they invest cryptocurrencies on the DAO, they

receive DAO tokens as a means to access to given functions (e.g., voting, exchange, propose changes) within the DAOs. The investors become contributors when they vote and validate the whitepapers and work on developing the DAOs' purposes through different activities and novel proposals. They are active contributors to the DAO governance and collective decision-making, mainly through off-chain governance mechanisms, such as voting, discussing the proposals, proposing new actions.

The **developers** contribute by creating, deploying, and developing the DAO whitepaper rules in a smart contract encoded on blockchain protocol. They also encode future changes and novel agreements (Buterin, 2014a).

The **miners** put their computers at the service of the blockchain infrastructure to verify, validate cryptocurrency exchange, also serve to validate and record DAO members' interactions within the organization, as for example buying, selling, and exchanging tokens, voting on proposals, etc. In blockchain, miners are cryptocurrency investors who use their computers to build distributed ledgers that record all interactions. “Mining” is automated through consensus algorithms to validate and verify transactions with immutable records (Swan, 2015; Van Rijmenam et al., 2017; Vergne, 2020; Wang et al., 2019).

Existing research on DAOs has also explored how new roles and tasks might emerge with future technological developments, making these communities more complex (Wang et al., 2019). Further, Islam et al. (2019) identified three main machine automated tasks that depend on machine algorithms and codes instead of human roles: (1) the blockchain that defines the set of rules through algorithms; (2) the marketplace or exchange of cryptocurrencies that enables connecting buyers and sellers; and (3) wallets, that is, the apps in which investors keep their cryptocurrencies.

3.2. Automated organizations: blockchain-enabled technologies

DAOs can be operationalized through automated rules defined by the DAO whitepaper but encoded in a smart contract stored and executed on the blockchain protocol. Smart contracts are programmable agreements based on computer code, also known as the ‘code-is-law’ principle (Lessig, 1999) or ‘law code’ (Hassan and De Filippi, 2017). The smart contract enables machine-based automated rules to be the core instrument for the operationalization of automated DAOs. regarding ownership, transactions, and messages between two or more contributors that execute themselves without any central authority (Lumineau et al., 2021). These encoded rules facilitate clear interactions, transparency, and distributed trust between DAO contributors (Wang et al., 2019).

The smart contract was first proposed by Szabo (1994) as a computerized transaction protocol that executes the terms of a contract on the digital space. The code controls the execution, transaction, and recording of relevant actions, so they become traceable and irreversible. In DAO, smart contracts monitor their components' evolution in a dynamic, proactive, and enforced way, becoming a list of successive processes and representing a security system to ensure that everything gathered in the software contract is enforced once it is deployed (Buterin, 2014a).

The literature stresses that the automated principle in DAOs cannot be separated from the ongoing development of blockchain-enabled technologies (Wang et al., 2019). It is difficult to understand DAO organizational shifts without understanding the technological developments that make up blockchain architecture (Campbell-Verduyn, 2018a; DuPont, 2018): (1) distributed ledger technologies (DLT), (2) machine consensus mechanisms, (3) intelligent matching, and (4) ongoing technological development.

First, blockchain technology was originally created as a distributed ledger that is a digital database (a chain) without a central administration (Nakamoto, 2009). A distributed ledger is a database that is shared and synchronized across multiple geographies, sites, and computers (Mattila and Seppälä, 2018; Sultan et al., 2018). P2P communities can

record and update transactions and smart contracts, archiving details on multiple computers using consensus mechanisms (Campbell-Verduyn, 2018, 2018a; De Filippi and Loveluck, 2016; Islam et al., 2019).

Second, distributed ledgers apply machine consensus algorithms to secure the content of transactions (cryptocurrency/token), or any type of data exchanged (Campbell-Verduyn, 2018a; DuPont, 2018; Hsieh et al., 2018a). These are based on asymmetric encryption and time-stamps to ensure that security requirements are met, and that DAO ownership is authenticated (Wang et al., 2019). The first blockchains and therefore DAOs mainly adopted Proof-of-Work (PoW) protocols, which require millions of computers connected across geographies, as they are nodes on the chain of distributed ledgers. The use of PoW involves the intensive consumption of energy across the planet, which has become a main criticism of blockchain technologies (DuPont, 2019). Currently, with the goal of reducing blockchain's environmental impacts and intensive energy consumption, blockchains are experimenting with other types of consensus mechanisms, such as proof-of-stake (PoS), practical Byzantine fault tolerance (PBFT), delegated proof-of-stake (DPoS), or hybrid consensus techniques (Wang et al., 2019).

Third, DAO uses AI-based intelligent matching, which enables not only the combining, matching, or connecting of peers within DAOs but also the matching of knowledge and reducing communication costs while improving efficiency in the network of nodes (Wang et al., 2019). Blockchain automatically matches different roles and tasks, digitizing information, as well as the behavioral data of different members (Wang et al., 2019). In so doing, DAOs can be more efficient when mobilizing and connecting people, identifying tasks, evaluating individual work, and enabling reputation and reward systems through tokens.

Finally, since Bitcoin's launch, blockchain technologies have evolved considerably and continue to change, incorporating AI, Big Data, and the Internet of Things (IoT) (Wang et al., 2019; Van Rijmenam, 2019). These technologies will continue to transform the organizational design and facilitate the future development of DAOs. For example, as Wang et al. (2019) claimed, incorporating AI will enable DAOs to encode new tasks that are still carried out by humans; as such, AI can facilitate in-depth learning within DAOs' networks of nodes (members). An example of these novel automated tasks could be the selection and prioritization of different opportunities and the adoption of goal-director capabilities (Wang et al., 2019). In the future, organizational scholars should understand the increasing capabilities of DAOs based on advanced technological development should understand the organizational implications is needed, this automation will enable the human supervision of distributed ledgers, reasoning, and decision-making to be replaced with encoded tasks.

3.3. Autonomous organizations: DAO governance through token economics

DAOs operate autonomously through the active participation of P2P community of contributors, using off-chain democratic rules and direct voting processes based on transparency and token incentives instead of bureaucratic systems (DuPont, 2019). In doing so, DAOs combine machine and human governance (De Filippi and Loveluck, 2016; Hsieh et al., 2018a). Machine governance is based on on-chain encoded and automated tasks in smart contracts. Complementing human governance is based on off-chain mechanisms that enable contributors to discuss and deliberate on new proposals through social media and on-line forums, submit proposals, vote to decide on which proposals they accept, and trigger collective community decisions (DuPont, 2018).

DAOs as autonomous organizations are also driven by tokens. Each DAO has created its own token—that is, a tradable asset or utility based on the cryptocurrency (DuPont, 2019). Tokens represent the “negotiable digital assets and the proof of rights and interests” of each DAO investor-contributor (Wang et al., 2019, p. 874). For example, DAO tokens give investors the right to vote on potential proposals and new projects. DAOs also use tokens to reinforce and incentivize contributors' behaviors and

involvement (Kazdin and Bootzin, 1972; Wang et al., 2019). In doing so, DAOs create their own reputation systems based on token exchanges that reflect the credibility and influence of token-holders in the organizations. A main research gap in DAOs is based on token incentives and reputational system.

3.4. Research gaps

The literature analysis shows important research gaps, which we summarize in Table 2. We have classified the research gaps based on each DAO principle. In the research of decentralization, as we have emphasized, the existing DAO literature has not yet reached a common view of a decentralized organization, thus indicating a lack of empirical and field research on DAO communities (DuPont, 2019). Researchers do not know in detail the performativity of DAOs, including an analysis of the different types of hierarchies that forms in the absence of a formal hierarchy (Kleinaltenkamp and Ansari, 2021). The existing literature also lacks an understanding of the complexity of the communities, roles, and tasks of DAOs that are connected to the impacts of powerful members, such as founders and developers (Hsieh et al., 2018a). Another main research gap is how the impact of DAOs on democracy and how DAOs undermine the capacity of central governmental authorities to supervise economic and commercial activities and DAO accountability (Atzori, 2017).

Research on automated organizations also reveals research gaps, such as the limitations of smart contracts and code-is-law and the future development of blockchain and other technologies (Wang et al., 2019). Another research gap is based on how DAOs will drive legislation about decentralized organization, including supervision and control and how DAOs have changed code-is-law (De Filippi and Wright, 2018). There is also a lack of research on the work and labor rights of DAOs regarding this automated tasks and token rewards systems (Wang et al., 2019).

Finally, there are research gaps to understand DAOs as autonomous organizations, such as the efficiency of embedded human-machine DAO governance and the empirical performance of off-chain deliberation and voting mechanisms and community decision-making (Hsieh et al., 2018a). A main gap is the analysis of the impact of the token economy on the DAOs' reputation system (DuPont, 2019), and the use of DAOs for illegal activities exploring ethical and democratic issues.

4. Theoretical perspectives informing DAOs and blockchains

In this section, we present our analysis of existing theoretical inquiries. The emergence of blockchains and DAOs has been studied mainly through four theoretical lenses, as illustrated in Table 3: transaction cost theory, the theory of institutions for collective action, agency theory, and sociomateriality theory. The first two theories are based on new institutional economics. Understanding these theoretical inquiries allow to explore DAO theory building.

4.1. Transaction cost theory

Transaction cost theory has been a key perspective applied to blockchain and DAO (Ahluwalia et al., 2020). New institutional economists have analyzed blockchain and cryptoeconomics as a novel institution that proposes a new way of “coordinating economic activity”; consequently, blockchain and DAO goal is to generate a “new type of economic institution” and organizations, with scholars exploring how it might transform the economic institution of capitalism (Davidson et al., 2018, p. 641). Blockchain technology decentralizes economic systems but also foments new economic coordination mechanisms that could replace “the economic coordination provided by markets, hierarchies, relational contracting and governments” (Davidson et al., 2018, p. 650). DAOs have also been studied through the lens of transaction cost theory, due to their capacity to reduce market-based transaction costs (Berg et al., 2019).

Table 3
Main theoretical perspectives applied to DAOs and blockchains.

	Transaction cost theory	Theory of institutions for collective action	Agency theory	Sociomateriality theory
Approach	DAOs reduce uncertainty and opportunism among investors by proposing a complete contracting model. They reduce transaction costs related to economic coordination by delivering an alternative form of disintermediate economic governance for P2P transactions.	DAOs work with the principles of collective action by which virtual community members adopt collective choice arrangements to design, discuss, and vote on the rules governing the software protocols and verify the exchange of shared resources.	DAOs introduce a different approach to principal-agent relations because the agent is automated by the cooperation of a distributed network of computers. They reduce the agent's problem of self-interest, which leads to the agency conflict of moral hazard.	DAOs' social and material agencies become interlocked and produce new forms of organizational design that enable P2P communities to act without human intervention. DAOs' sociomateriality includes (1) sociomaterial practices and interaction, (2) human-machine agency, and (3) institutional change.
Main authors	Ahluwalia et al. (2020), Berg et al. (2018, 2019), Catalini and Gans (2019), Davidson et al. (2016, 2018), Miscione et al. (2018, 2019), Meunier and Zhao-Meunier (2019), Murray et al. (2021, 2021a), Lumineau et al. (2021), Shermin (2017), Tapscott and Tapscott (2017), Wright and De Filippi (2015), Zachariadis et al. (2019)	Berg et al. (2018, 2019), Davidson et al. (2016, 2018), De Filippi and Loveluck (2016), Hsieh et al. (2018), Miscione et al. (2018), Pazaitis and De Filippi (2017), Rozas et al. (2021), Wright and De Filippi (2015)	Arruñada and Garicano (2018), Beck et al. (2018), Berg et al. (2018, 2019), Hsieh et al. (2018, 2018a), Kaal (2019), Kotsialou et al. (2018), Iansiti and Lakhani (2017), Islam et al. (2019), Lumineau et al. (2021), Murray et al. (2021, 2021a), Nabilou (2020), Shermin (2017), Sheth and Subramanian (2019), Tapscott and Tapscott (2017)	Kifokeris and Koch (2020), Murray et al. (2021a), Lumineau et al. (2021), Swan and Brunswick (2018), Van Rijmenam (2019), Van Rijmenam et al. (2017), Van Rijmenam and Logue (2021)
Main topics of research	Institutional change Changing capitalism	Institutional rules Governance Organizing for collective action	Community governance: roles Management On-chain/off-chain actions	Human-machine entanglement
Research gaps	Impact of smart contracts New transaction costs created by DAOs Impact of code-is-law Impact of institutional cryptoeconomics on capitalism, DAOs, labor, and banking regulations Transforming hierarchies and decentralized in business, democracy, and society Impact of distributed trust and decentralized power Concept of responsibility in DAO experimentation	Impacts of novel pool of resources: cryptocurrencies and token economies DAOs as institutions for collective actions, novel power relationships, and new hierarchies Human and machine governance in DAOs New digital forms of collective decision-making and voting rights Emergent collective agreements and smart contracts Ethical issues regarding DAOs Impact of DAOs on democracy	Impact of automated principal-agent relationships in DAOs Human-machine agency Power distribution Token remuneration, reputation, and rewards Replacing human supervision with distributed ledgers and smart contracts New forms of reasoning and decision-making	Impact of advanced information technologies and blockchain technological development on human-machine agency Performativity: Human-machine agency in DAOs and the evolution of organizational design Labor in DAOs Actor network practices and interactions in DAOs Institutional change

As a novel institutional technology, blockchains allow for the development of cryptoeconomics and new types of automated agreements (between those who propose the contract and the recipients) based on self-executed contracts (smart contracts), and then develop decentralized, automated, and autonomous organizations (DAOs) to solve the challenges of incomplete contracts, as studied by Williamson (1979) (Berg et al., 2019). While hierarchies and markets exploit incomplete contracts and relational contracting to overcome opportunism and uncertainty (Davidson et al., 2018), DAOs aim to minimize this opportunism by proposing a “complete contracting model” that automatically executes and enforces agents' relationships, thereby reducing transaction costs and avoiding hierarchies (Davidson et al., 2018, p. 51).

While Williamson (1979) connects transaction costs to long-term contracting, including ex-ante and ex-post costs and assuming bounded rationality (limits to the human condition) and opportunism, blockchain and smart contracts aim to enhance a system of organizing “without opportunism” and “bounded rationality” (Berg et al., 2019, p. 26). Because of blockchain mining, DAOs minimize the use of intermediaries and aim to diminish fraud, arbitration, and enforcement costs and reduce ex-post opportunism and costs that can be embedded in smart contracts.

However, there are important limitations and research gaps to this approach. For instance, Meunier and Zhao-Meunier (2019) emphasize the limits of lack of transaction costs in blockchains and DAOs, claiming that blockchains are traditional markets designed by networks (developers) but executed by hierarchies (miners); thus, there is no real decentralization. They also claim that, although blockchains and DAOs empower users to preserve their data and implement actions through cryptographic keys, they also imply lower performance, higher

coordination costs, and the transfer of risks to users (Meunier and Zhao-Meunier, 2019). Murray et al. (2021) argues that blockchains reduce cryptocurrency transaction costs but introduce new transaction costs that emerge due to (1) inflexibility stemming from a lack of discretion in applying smart contract preprogrammed rules; (2) oracle rules that involve new costs when information intermediaries provide incorrect data; and (3) the security costs of ensuring the safety and reliability of blockchain protocols. Another important issue is related to ex-ante costs stemming from, for example, smart contract designers potentially committing fraud when designing those contracts (Berg et al., 2019); similarly, after codifying smart contracts, ex-post events, such as disputes between developers, miners, and users, cannot be resolved by smart contracts.

4.2. Theory of institutions for collective action

The second theoretical lens applied to study blockchain and DAO is the theory of institutions for collective action, as originally proposed by Ostrom (1990), for local common-pool resources; that is, limited resources shared by a community of users and/or owners. In terms of blockchain and DAO, this analysis includes new institutional economists, such as Berg et al. (2019), Davidson et al. (2016), Howell and Potgieter (2019), Pazaitis and De Filippi (2017), and Rozas et al. (2021). The theory of institutions for collective action explains how local users of common-pool resources (e.g., lakes and forests) develop design principles to self-govern those resources and avoid self-interested behavior (Ostrom, 1990). Design principles are the basic rules of self-governance (Ostrom, 1990).

The theory of institutions for collective action has expanded to include knowledge commons and common-pool resources in the digital

space (Ostrom, 2003). While the process of pooling common resources in the digital environment has always been characterized by openness and infinite replicability, blockchains solve rivalry in open digital environments via the distributed verification of transactions and smart contracts (Miscione et al., 2018).

Therefore, scholars have studied blockchains and DAOs as institutions for collective action that include the following main elements: community self-governance, common pools of resources (cryptocurrencies/tokens), design principles (smart contracts), automated collective actions (developed by software protocols and distributed ledgers) and avoiding self-interest due to programmed rules (Howell and Potgieter, 2019; Rozas et al., 2021).

Blockchains and DAOs reinforce the community-based governance concept adopted by open-source software communities (O'Mahony and Ferraro, 2007) but expand to decentralization to include automated rules and dehierarchization (Sigh and Kim, 2019). This is what is referred to as "machine consensus" or "on-chain governance" (Hsieh et al., 2018, 2018a), which connects to Ostrom's design principles. DAOs include community-based governance (off-chain governance), and in this respect, scholars have primarily focused on analyzing human deliberation and voting rules (Hsieh et al., 2018a). DAOs off-chain mechanisms can be considered the collective-choice arrangements by which P2P virtual communities deliberate, propose, and vote on design principles (Ostrom, 1990). The main challenge emphasized by researchers with DAOs arises in analyzing community decision-making and understanding whether new hierarchies and forms of authority emerge, as in the case of open-source communities (O'Mahony and Ferraro, 2007). Collective action theory emphasizes ethical issues (e.g., fraud, corruption, lack of taxation, labour rights and common good) (Sulkowski, 2019), the impacts on democracy, and the ecological impacts of DAOs (e.g., overuse of energy through distributed ledgers and proof of work as a machine consensus mechanism) (DuPont, 2019).

4.3. Agency theory

The third perspective is agency theory (Beck et al., 2018; Hsieh et al., 2018; Murray et al., 2021; Nabilou, 2020; Shermin, 2017). Agency theory is based on corporate governance analyzing ownership and control of owners or investors over managers, which results in autonomous management (Fama and Jensen, 1983). This agency relationship occurs when the "principal" (owner) delegates work to the "agent" (manager) through contractual arrangements established within corporations. Agency theory explores this relationship and the problems that arise when the agent and the principal have different goals and attitudes toward risk. This issue is known as the principal-agent problem and emerges when the agent is empowered to make decisions on behalf of the principal and act, at the same time, in the agent's self-interest and counter to the principal's interests due to the asymmetry of information or conflicts of interest (Eisenhardt, 1989).

Blockchains and DAOs coordinate decentralized open networks using a nexus of combined smart contracts that replace the control and authority of managerial hierarchies. Specifically, DAOs negate the existence of any central authority and spread ownership through pseudo-anonymous networks (Iansiti and Lakhani, 2017), where "there is neither a clear division of powers or roles, nor even a clear division of labor" (Nabilou, 2020, p. 8). It is difficult to see this separation between ownership and management, as all DAO contributors (developers, miners, and investors/users) own cryptocurrencies and tokens (Nabilou, 2020).

By contrast, blockchains and DAOs enable new ways of dealing with the principal-agent relationship (Kaal, 2019). According to Kaal (2019), Shermin (2017), and Tapscott and Tapscott (2017), blockchains and DAOs apparently solve the principal-agent problem (Hsieh et al., 2018) because the relationship between users or contributors (principals), miners, and developers (agents) is automated and because blockchains and DAOs represent the same group of agents. Smart contracts and

consensus mechanisms enable automating the principal-agent relationship by encoding ownership and management governance rules (Buterin, 2014a). This reduces opportunistic behaviors between the parties (Hsieh et al., 2018a; Tapscott and Tapscott, 2017), eliminates the need for principals to monitor and control agents (Murray et al., 2021), and provides integrity and transparency to all the data affecting the principal-agent relationship (Yermack, 2017). All these efficiencies mitigate the costs associated with intermediaries and agents (Kaal, 2019). Important challenges appear in the analysis of replacing human supervision of agents with distributed ledgers and smart contracts and new forms of reasoning and decision-making (Islam et al., 2019).

The main counterargument to this theory applied to blockchains and DAOs is that the principal-agent problem becomes more complex instead of being eliminated (Murray et al., 2021). The agent role on blockchains and DAOs are based on automated work that does not require the supervision of investors; however, for example, developers' power increases because they oversee the development of the software that supports the relationship between principals and agents (Kotsialou et al., 2018). Another problem is if a group of miners takes control of the blockchain (51 % network attack) (Antonopoulos, 2014), reversing transactions and smart contracts and provoking security risks and errors in the system for investors/users, miners, and developers (Murray et al., 2021). Similarly, a future challenge might arise if developers attempt to change the rules that govern the blockchain on which DAOs are built or influence miners, users, or other developers; in this case, the miners would be key to verifying possible changes in the software protocols governing the blockchain (Trump et al., 2018).

4.4. Sociomateriality theory

A final theoretical inquiry is based on sociomateriality theory (Orlikowski, 2007). The sociomateriality view aims to understand "blockchain-DAO constitutive entanglement" through which original human-to-human interactions are amplified by including human-to-machine interactions or machine-automated rules (Orlikowski and Scott, 2008).

Sociomateriality theory thus explores how the social realm shapes the use of the materiality of technology, and vice versa (Orlikowski, 2007). It combines materiality with institutional change and examines how the DAO movement has generated new practices and interactions, human-machine agency, and institutional change (Leonardi, 2012). First, blockchain-DAO entanglement implies mutual interaction between human practices and technological boundary-spanning (Orlikowski and Scott, 2008). DAOs use consensus algorithms to enable machines to carry out collective supervised actions in a decentralized fashion without central managerial control (Hsieh et al., 2018). Second, the sociomaterial assemblage between blockchain technology and DAOs enables virtual communities to experiment with novel forms of human-machine agency with on-chain (encoded) and off-chain (human) governance mechanisms (Hsieh et al., 2018a; Orlikowski, 2007). Third, blockchain-DAO entanglement represents a new organizational design that has the ability to bring institutional change to the economy, business, society, and democracy supported by cryptocurrencies and tokens. DAO generates novel norms of economic exchange and decentralized organizing, referred to as "institutional cryptoeconomics" (Berg et al., 2019). DAOs are not only a technology or an organizational design; rather, they represent new norms that shape human behavior based on collective action (Ostrom, 1990).

Our research shows three main sociomateriality components that emerge from DAOs:

DAO sociomaterial practices and interactions refer to the analysis of the evolving P2P discursive, relational and material practices and interactions in DAOs, exploring the main challenges regarding the performativity of this new organizational form (Kleinaltenkamp and Ansari, 2021). Some of these practices are deliberation, decision-making, voting, matching, information sharing and exchange, token rewards,

transactions, code-is-law and accountability (Islam et al., 2019).

DAO human-machine agency refers to the analysis of the entanglement between human and machine agency at DAO, raising new questions about decentralized and automated agency, and the analysis of emerging hierarchies. DAO agency also focuses on the distribution of power distribution and control, and defining new forms of work, leadership, governance and decision-making (Van Rijmenam, 2019).

DAO institutional change refers to how DAOs create novel norms of organizations that guide human cooperation and economic interactions based on cryptocurrency exchanges and token rewards and incentives (Van Rijmenam, 2019). DAOs support socio-technical changes that enable new forms of business and economic exchanges, driving institutional change, decentralized democratic governance. Institutional change driven by DAOs bring important emerging ethical challenges about DAO regulation and accountability (Berg et al., 2019).

5. DAOs and future directions for research

As a result of the literature outcomes, we explore future directions for research. We first propose an integrative model of DAO for research and theory building. We then propose a research agenda.

5.1. Integrative model for DAO research and theory-building

Based on our critical analysis of the literature, we propose an integrative model of DAO (Torraco, 2005). Our model combines two main intertwined dimensions: (1) the three sociomaterial entanglement dimensions; and (2) inquiry at the intersection between the other three theoretical perspectives (Fig. 2).

At the center of the model, we propose the sociomaterial entanglement examining how DAOs continuously adapt and create new practices and interactions generating performativity and actor network practices (Islam et al., 2019). DAOs thus have the potential to build decentralized

ecosystems, with P2P communities that work on decentralized organizations, adopting new interactions based on token reputation and rewards, data sharing techniques and matching (Van Rijmenam, 2019). Some research emphasizes how the development on human-machine agency is at the core of DAOs generating novel work based on chain and off chain governance (Hsieh et al., 2018). As a result of this sociomateriality, scholars include DAO as part of large institutional change driven by blockchain and cryptoeconomics (Berg et al., 2019).

We extend this with dimensions with the analysis from other theories and propose pathways for theory building. We examine the intersection between the theoretical perspectives exploring the sociomateriality entanglement. The interconnections between theories help to understand the main research topics, challenges, and future research streams.

The first theoretical extension emerges at the intersection between the theory of collective action and transaction cost theory, both institutional theories. This intersection focuses on the study of decentralized institutions and organizations and exchange, and the impact of DAOs on institutional change (Berg et al., 2019; Davidson et al., 2018; Rozas et al., 2021). We argue that the relationships between these theories promote research and conceptualization of new institutional economics by studying how DAOs enable decentralized institutions: new forms of collective action based on new self-executed smart contracts that reduce transaction costs in cryptocurrency and token economics. Research shows how DAOs aims to minimize managerial hierarchies and reduce transaction costs by adopting machine automated tasks and promoting community collective decision-making (Berg et al., 2019; Lumineau et al., 2021). DAOs attract investors via two separate dynamics: (1) transforming the investment, exchange, and transactions built on cryptocurrency investment and (2) building organizations by adopting token incentives and developing open-access digital communities that enable sharing collective goals and new projects to transform collective decision-making, crowdfunding, and collective intelligence (Hsieh et al., 2018; Rozas et al., 2021). Future theory building can extend the impact

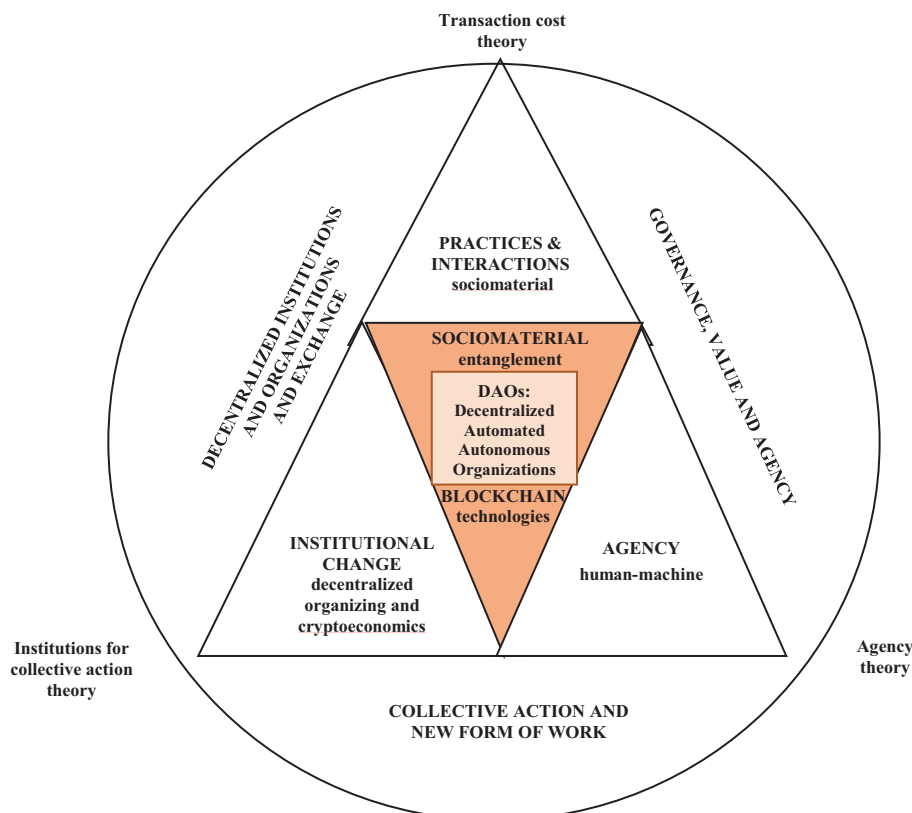


Fig. 2. Integrative model of DAO research and future theory building.

of blockchain and DAO movement revisiting the main rules of economy and proposing new decentralized organizations and institutions that enable new forms of exchange. DAO theory is driven by performativity (Kleinaltenkamp and Ansari, 2021; Vergne, 2020) exploring the ability of emerging technologies, such as data analytics, and AI, to leverage efficient design of DAOs that might be able to substitute current hierarchical or centralized businesses and institutional rules (Ahluwalia et al., 2020; Murray et al., 2021, 2021a).

The second theoretical extension is based on the intersection between transaction cost theory and agency theory. It offers a novel conceptualization of *governance*, *value*, and *agency* in DAO, including how digital and distributed P2P networks govern community decision-making to create and distribute value while reducing the cost of economic transactions (Murray et al., 2021). This allows the study of new types of digital decentralized services produced in DAOs, such as traceability in supply-chain management (Kimani et al., 2020), new venture capital projects, new forms of charity and entrepreneurship, new forms of virtual worlds on metaverse (Tapscott and Tapscott, 2016). This enables to theorize about DAOs and new digital and decentralized business models transforming mainstream markets. Business and management scholars have explored the emergence of novel costs associated with smart contracts (Murray et al., 2021). Compared to traditional agency theory in corporations, DAO facilitates the analysis of human-machine agency with automated and autonomous mechanisms of governance and blur the boundaries between DAO members who simultaneously act as investors and managers, and agents and principals (Lumineau et al., 2021). Future research should investigate the development of human-machine agency in DAOs to define novel value-creation structures and business models (e.g., metaverse, crowdfunding for new ventures, or the metaverse), novel forms of work and labor.

The third theoretical extension emerges at the intersection of agency theory and institutions for collective action theory. We argue that the interconnection between these theories offers a novel conceptualization by studying DAO as a novel form of organization for *collective action* and *new forms of work*. In line with institutions for collective action (Ostrom, 1990), this approach allows to understand DAOs as P2P communities that govern a pool of resources (cryptocurrencies and tokens) without hierarchies and management (Rozas et al., 2021). In addition, and connected to agency, DAO smart contracts are similar to design principles (Ostrom, 1990) that define collective rules by encoding machine-performed tasks enabling human-machine agency. But there are also important differences between DAO and collective action as DAOs and cryptocurrencies can also drive self-interest (Davidson et al., 2016), and unethical or illegal behavior (Sulkowski, 2019). Future theory building can explore how P2P contributors manage these common-pool resources and what are their main overarching goals (e.g., common good, business, charity). Further, novel research is needed to understand and transform the concept of work with new roles and automated tasks encoded in smart contracts how this token system facilitates collective action or drives self-interest (Wang et al., 2019). As a result, there are important elements of DAO that emerge through the implementation of cryptocurrency economics that should be examined (Berg et al., 2019). Future theory building should also tackle how DAO poses important risks to democracy and nation-states by generating important ethical issues, such as their use for illegal activities (Hsieh et al., 2018a), lack of accountability and ecological challenges.

5.2. Research agenda

This section proposes a research agenda that flows logically from the literature review and theory-building analysis. We build the research agenda at the intersection between the DAO principles of decentralization, automated and autonomous, and explore the dimensions of sociomateriality, which include sociomaterial practices and interactions, human-material agency, and institutional change for decentralized institutions and cryptoeconomics. In doing so, we explore different

research opportunities. Table 4 presents the main summary.

5.2.1. Sociomaterial practices and interactions

The analysis of sociomaterial practices and interactions reveals three potential research streams that connect decentralization with the

Table 4
Research agenda.

Decentralized autonomous organizations research streams			
Main dimensions of the sociomaterial view	Decentralized Generate organizations and self-organized communities without a central hierarchy	Automated Based on 'code-is-law' that enables encoding tasks and interactions and deploys encoded operational rules and automated governance tasks	Autonomous Based on human and community governance and democratic participation, enabling autonomous decision-making, trust-building, and collaborative work
Practices and interactions Sociomaterial	<i>Performativity:</i> Analysis of the performativity of DAOs as a new form of organization that allows for the study of experimentation, including failures and success, problems with weak hierarchy, security issues in blockchain technologies, and empirical research on DAOs communities	<i>Regulation and accountability:</i> Analysis of DAO internal and external regulation. Understand DAO automated rules based on 'code-is-law' Research on DAO-specific legal status within the economy and society. DAO accountability	<i>Transaction costs, token rewards and incentives systems:</i> Analysis of smart contracts, and the minimization of transaction costs understanding the token reputation system in DAOs: incentives and reward mechanisms
Agency Human-machine	<i>Power distribution and control:</i> Understand power distribution and de-hierarchization in DAO communities, including trust building and conflict resolution	<i>Work, hierarchy, and leadership:</i> Understand type of work and labor rights in DAOs as a new organizational form Active members that provide voluntary work, roles, time, resources, and capabilities Analysis of different emerging hierarchies and leadership in DAOs	<i>Governance and decision-making:</i> Analysis of governance processes and community decision-making Exploring off-chain mechanisms and the use of social media, deliberation, and voting mechanisms
Institutional change Decentralized institutions and cryptoeconomics	<i>Socio-technical transformation:</i> Understand the goal of the DAO movement, and the societal impacts of cryptoeconomics and decentralized organizations	<i>Business and economics:</i> Analysis of DAOs' applicability and scalability in business, value-creation and business models	<i>Ethics and democracy:</i> Understanding the ethical implications of DAOs, including illegal uses, cryptocurrency institutions, human rights, governance, democracy, digital voting rights or ecological costs

performativity of DAOs, automated with regulation and accountability, and autonomous with transaction costs, token rewards, and incentive mechanisms:

1) Performativity.

Performativity is central to sociomateriality theory (Orlikowski and Scott, 2008), and it is key to understanding the development of DAOs, decentralized organizing and value creation (Kleinaltenkamp and Ansari, 2021). It refers to how the entanglement between technologies and human action and DAOs not only generates new theory, but also produces a new social reality: a new form of organization (Van Rijmenam, 2019). The development of smart contract blockchains have allowed for experimentation on decentralized organizations, enabling P2P contributors to test and learn. There are two intertwined levels of experimentation: (1) developers experiment with the growing blockchain-enabled technologies and cryptocurrencies, and (2) investors that become contributors (or members of the P2P community) experiment with new roles, actions and goals, for investment and economic exchange, societal needs or creativity.

Performativity emphasizes the analysis of DAO failures and success, including the implementation of novel technologies, experimenting with machine and automated rules and smart contracts, and human off-chain governance. First, as mentioned, blockchains and DAOs have suffered from important security code failures (e.g., due to hackers attacking cryptocurrencies) and other problems with security vulnerabilities, timestamps, transaction-ordering dependence, etc. (Wang et al., 2019). Some scholars argue that these vulnerabilities are a main challenge for DAOs' long-term permanence, while others argue that these failures can eventually be resolved with the development of more secure technologies, such as quantum computing (Lumineau et al., 2021), Big Data, or AI (Wang et al., 2019). Resolving these failures will enable the future potential of DAO. Kleinaltenkamp and Ansari (2021) have already applied performativity to understand blockchain failures, showing how there are important challenges between blockchain's technological features and its organizational outcomes, and emphasizing the failure of blockchain technologies to generate distributed trust and distribute power and equal authority among all DAO members.

Second, the study of DAO projects and whitepaper performativity shows the main goal of DAO founders including crypto anarchist (Atzori, 2017; DuPont, 2019) and P2P networks enabling business, economic, and institutional change (Berg et al., 2018; DuPont, 2019). Many founders of DAOs (e.g., DAOstack, Moloch, Aragon) use institutional theories (collective action and human-machine agency) to justify and develop this novel form of decentralized organizations and institutions (DuPont, 2019). To understand social performativity, researchers might carry out field research and ethnographic analyses of DAO communities to understand the main socio-symbolic objects including discursive theories, concepts, artifacts, goals, and values adopted by their founders, investors, and developers (Barad, 2003; Orlikowski and Scott, 2008). Regarding future opportunities for empirical research, we emphasize the need to study the communities in which DAOs emerge and to understand their goals, values, and work. There is a need for DAO community field research to explore how social-symbolic work shapes DAO communities, including new practices and interactions and building symbolic objects that involve sensemaking through language and other symbolic expressions. In this context, the analysis of DAO social media, whitepapers, documents, and secondary data offers new ways of understanding DAOs' organizational form and socioeconomic impacts.

2) Regulation and accountability.

The second research stream is based on an analysis of the impacts of DAOs on regulation and legislation, including (1) internal regulation and smart contracts (code-is-law), (2) broader commercial, economic and societal legislation and (3) DAO accountability. Wang et al. (2019,

p. 876) argue that a "semantic gap" exists between DAOs' encoded rules in smart contracts (internal code-is-law that DAO founders have deployed) and the legislative challenges that DAOs face in society and economy—how they adapt to mainstream Corporate Law, Contract and Security Law, Civil and Commercial Law. DAOs represent a novel type of virtual organization that generates legal gaps when operating in different markets and jurisdictions (Wang et al., 2019, p. 876). DAOs currently lack a specific legal status. A main question emerges to understand how nation-states will adopt legal, commercial legislation and supervision, which DAO communities aim to avoid. This lack of regulation also affects blockchains, cryptocurrencies, and tokens. The analysis of DAO and regulation involves two main research focuses: first, an analysis of the organizational rules adopted by P2P communities that are encoded in smart contracts or 'code-is-law' (De Filippi and Hassan, 2016; Lessig, 1999); and second, an examination of how DAOs impact external legal systems and corporate regulations (e.g., banking, investment, and business). Thus, DAOs are alegal in many jurisdictions and countries. As a result, DAOs have no legal responsibilities or obligations, which implies significant difficulties in terms of their accountability (Murray et al., 2021). Vergne (2020) investigated the implications of a blockchain platform economy as a dystopia compared to the sharing economy and digital platforms. Hence, future research should explore how governments aim to regulate cryptocurrencies and DAOs and how these efforts will affect their functioning to prevent illegal activities and competition.

3) Transaction costs, token rewards and incentive systems.

The consolidation of DAOs also requires an in-depth understanding of the implications that smart contracts and other technologies have on reducing and minimizing transaction costs and transforming exchange and incentive mechanisms using the token economy (Hsieh et al., 2018; Murray et al., 2021). Most encoded and automated rules that enable the autonomous governance of DAOs are based on smart contracting issues that can change and are proposed by the contributors but are mainly controlled by the knowledge of developers and founders (DuPont, 2019). Current research has looked at how the lack of flexibility within smart contracts and machine consensus is a major challenge for the future evolution and adaptation of DAOs (DuPont, 2019; Hsieh et al., 2018a). The lack of flexibility in terms of automated rules increases smart contract costs (Murray et al., 2021). New costs also arise due to the difficulty of removing human participation from smart contract execution without generating uncertainty and increasing the costs of specialized arbitration, conflict resolution, and post-contract execution (Murray et al., 2021). A second main area of research on DAOs is the token reward and incentive system based on token economics (Wang et al., 2019). There is a lack of research on DAO contracting processes and token-reward systems, as well as on value management and DAO reputation systems (Wang et al., 2019), which requires future research.

5.2.2. Human-machine agency

The analysis of human-machine agency is core to understanding DAOs as a new form of organizing and reveals three research streams that connect the issues of decentralized organizations with power distribution and control, automated rules with work and leadership, and autonomous with governance and community and collective decision-making.

1) Power distribution and control.

Although collective action theory connects decentralization with power distribution (Ostrom, 1990), it is not clear how this works in DAOs. While DAO principles emphasize de-hierarchization, there is no clear path regarding how DAOs distribute power among different community members. It is also not clear whether they really enable lack of hierarchy, for example, in terms of how off-chain human governance

processes work and whether some contributors have more influence than others (De Filippi, 2019). Scholars have explored DAO governance (Hsieh et al., 2018a), cojoined human-machine agency (Murray et al., 2021a), and the difference between distributed and decentralized organizations (Vergne, 2020). However, few have analyzed human governance in DAO communities in terms of new proposals and voting or evaluated how power is distributed among different types of clear top-down and executive hierarchy (DuPont, 2019). The analysis of the literature shows how the development of DAOs is full of conflicts between founders and contributors, and that some signals of power concentration exist among leading founders, contributors and developers (DuPont, 2019; Singh and Kim, 2019; Wang et al., 2019). Research has also shown that cryptocurrency platforms do not equally distribute power among investors (Hsieh et al., 2018a). Although they claim decentralization, control is partly exercised by the original software developers and miners who control major technological development and knowledge of DAOs and blockchain technology. Future research on power distribution and control requires the attention to issues such as accountability, conflict resolution, monitoring systems, and trust-building.

2) Work, hierarchy, and leadership.

The development of DAOs also requires analyzing work in DAOs. DAOs transform labor and drive voluntary work in decentralized P2P communities without managers and managerial hierarchies, while the benefits of contributors are based on cryptocurrency investments, and a rewarding system of tokens. DAOs' operational rules generate new roles and tasks different from those found in centralized digital platforms, businesses, and organizations (Orlikowski and Scott, 2008). DAO contributors are active members who voluntarily provide their work, time, knowledge, and resources. In this sense, DAO agency requires new roles and task divisions, as for example matching and token reputation. DuPont (2019) argues that human labor is managed by algorithms that produce reliable results and distributed trust. As a result, labor is based on collective intelligence, sharing knowledge, and ambitious goals. The growth of DAOs has created new institutional logics with symbolic meaning and material practices that shape novel labor and behaviors. A second main research stream on DAOs is the analysis of leadership and whether decentralization generates new types of leaders and novel forms of hierarchies that drive the development of new DAO-leading members, founders, and contributors. Currently, most DAOs have been adopted by founders pioneering blockchain platforms (e.g., Moloch, Aragon), committed to the cryptocurrency movement, Bitcoin and Ethereum (DuPont, 2019). DuPont (2019) describes how DAOs result in novel leadership adopted by well-known developers who, in some cases, can exercise implicit control. The developers who launch the DAOs originally know more about the principles and smart contracts' rules, having many advantages in terms of controlling future developments in those DAOs. New leaders and dominant groups might emerge among those who devote time and effort to these initiatives (DuPont, 2019), thus enabling different types of hierarchy based on horizontal networks, influence, knowledge, and reputation.

3) Governance and decision-making.

The third research stream requires studying governance processes as a key function that enables community decision-making, driving empirical research (Wang et al., 2019). As mentioned, governance is based on a dual system of on-chain and off-chain governance processes, and this generates complexity (Hsieh et al., 2018a). Governance requires continuous and iterative upgrades of both processes. Machine governance (on-chain) includes consensus mechanisms, smart contracts and intelligent matching, something which should be coordinated with off-chain collaboration. More research is needed to understand how smart contracts moderate the complex relationship between network nodes

through protocols and interfaces to reinforce off-chain governance processes. Exploring DAOs' off-chain governance requires the analysis of active engagement and participation by investors and contributors in democratic debates and voting processes using digital hubs, social media, and other instruments. There are many challenges to DAO governance regarding digital voting and online communities (Atzori, 2017; Hsieh et al., 2018).

5.2.3. Institutional change

The third main dimension of sociomateriality is how DAOs promote new institutional change based on the growth of decentralized institutional and institutional cryptoeconomics (Berg et al., 2019). There are many issues about DAOs and institutional change. We propose studying how DAOs connect decentralization to socio-technical transformation, automated to business and economy transformation, and autonomous to ethical and democratic challenges.

1) Sociotechnical transformation.

The growing DAO movement was drawn from cypher and libertarian philosophy, which resulted in bitcoin and the development of cryptocurrencies (Berg et al., 2019; Wang et al., 2019). This movement is growing in terms of cryptoeconomics, but it has generated many challenges and criticism (DuPont, 2019). Currently, DAOs are emerging, promoted by networks of digital communities, but they have not attracted mainstream businesses, policy, or society in general. Different projects can be organized as non-profit organizations, foundations, commissioned companies, or for-profit businesses (Wang et al., 2019). Therefore, future research should investigate how the DAO movement will evolve and broaden its impact on the creation of new decentralized institutions (Berg et al., 2019). The main question is whether DAOs can change organizations and generate novel norms and rules in society weakening nation-states (DuPont, 2019) and promoting socio-technical changes. As argued by DuPont (2019, p. 199), DAOs are "capable of supporting collective action at a tremendous range of scales – from smallest company to nation states." Therefore, it is important to analyze how DAOs might evolve, grow, and potentially bring about institutional change. Future research should analyze the novel forms of discourse and language created by DAO communities and explore sense-making regarding DAOs, that is, how people give meaning to this collective experience to build novel decentralized organizations transforming society and technological development. Future research might also explore whether the promise of new decentralized organizations within blockchain platforms has become a mainstream movement that supports large sociotechnical changes (DuPont, 2019; Lumineau et al., 2021).

2) Business and economic transformation.

The second research stream should focus on exploring how DAOs will impact decentralized businesses and the economy, bringing new decentralized products and services, non-profit projects, and business models. As explained above, DAOs have been adopted mainly by digital open-source P2P communities, providing a decentralized approach to digital platforms. DAOs currently have a limited range of applications in business, mainly in cryptocurrency investments (e.g., bitcoin) and joint venture funds (e.g., MolochDAO). However, there are new emerging projects using the DAO form that support the development of virtual reality metaverse platforms (e.g., Decentraland), public digital democracy (e.g., Earth Democracy), communities that spring up around artwork (e.g., ApeCoin), and communities that raise funds for humanitarian actions (UkraineDAO), though their impact is currently slight. A key future research topic is the application and scalability of DAOs to business value creation and decentralized business models (Kimani et al., 2020; Tapscott and Tapscott, 2016) and the development of the decentralized platform economy and decentralized businesses (Vergne, 2020). Thus far, businesses have applied blockchain to manage

collaboration with suppliers in global supply chain management efforts (Gaur and Abhinav, 2020), cross-organizational cooperation (Lumineau et al., 2021), and novel business models and logistics (Mattila and Seppälä, 2018). A main question is how DAOs can lead to new sources of decentralized value and business models (Kimani et al., 2020). Some businesses have already adopted blockchains in multisided markets, where production and distribution are supported by networks of contributors with incentives to cooperate and collaborate, despite tensions between them (Lumineau et al., 2021). Large corporations have also used blockchains to adopt supply chain management tools (Kopyto et al., 2020). These include those providing digital authenticity and those that guarantee the immutability of smart contracts and documents with all their suppliers (e.g., Emerson, Hayward, IBM, Mastercard, and Maersk), applying blockchain technologies to manufacturing, retailing, technology, and financial services (Gaur and Abhinav, 2020). Banks, companies, and governments have also started to test blockchain technologies and the use of smart contracts (e.g., AgUnity). Future DAO research requires an understanding of DAOs' transformative role across the private sector and the economy.

3) Ethics and democracy.

There are also important research gaps regarding DAOs' from an ethical and democratic perspective. There is a dual nature of DAOs. Some scholars emphasize the use of DAOs for the common good and collective action (DuPont, 2019), including their impact on democracy, human rights, sustainability, and grand challenges (Sulkowski, 2019). Others explore the possibility of DAOs being used for potentially criminal and illegal operations and practices, for example, money laundering, terrorism, and unethical conduct, such as carrying out anonymous and illegal transactions through cryptocurrencies (Lumineau et al., 2021; Vergne, 2020). Therefore, the challenge of DAOs is the use and this demands for accountability.

Political and ethicist scholars have shown how DAOs can have a positive impact on human rights and organizational transformation connected to technological utopianism and digital democratization (Atzori, 2017; DuPont, 2019). DAOs might complement digital mechanisms in democracy by increasing virtual efficiencies and reducing intermediaries in voting and decision-making; however, this raises important questions about decentralization and the role of the state in promoting stateless movements (Tapscott and Tapscott, 2016, 2017). Although some original DAO developers (Buterin, 2014) envision full democratic and decentralized organizations, the development of these organizations has not been perfect, and their growth provokes numerous ethical concerns about this novel organizational design, which raises important questions about the DAO utopia for organizational transformation. Thus, scholars need to adopt a critical approach to DAOs, cryptocurrencies, and blockchains (DuPont, 2018; Hsieh et al., 2018a). To cope with these deficiencies, novel research (Tang et al., 2020) should develop an ethical framework for blockchains and DAOs. In summary, while we cannot axiomatically study or differentiate between "good" and "bad" forms of DAOs, future research can explore what constitutes good or bad democratic, ethical, and collective decision-making practices. Another main research challenge is the ecological impact of machine consensus mechanisms, mainly proof-of-work, which requires millions of computers connected to validate and verify a distributed ledger. Blockchain mining generates significant energy consumption concerns and other challenges for DAOs due to their ecological impact (Sulkowski, 2019).

6. Conclusion

We conducted this literature review to provide conceptual clarity on DAOs and to explore pathways for theory building and directions for future research. The development of DAOs as a novel form of decentralized organizations enabled by blockchain technologies brings

multiple potential to virtual P2P communities working without a central management hierarchy, substituting third-party supervision with automated rules, and machine algorithms (DuPont, 2019). DAOs is part of cryptocurrency economics and decentralized institutional change (Berg et al., 2019). The growing of DAOs has driven new research on this new organizational form that integrates the entanglement between blockchain-enabled technology and decentralized, automated, and autonomous governance in organizations. This new research has also prompted the analysis of DAOs main technological failures, community governance challenges, decentralized business opportunities, accountability and ethical concerns.

This paper makes three main contributions. First, we provide conceptual clarity of the DAO principles and performance. Second, we explore the main theories that scholars have applied to understand this novel organizational form, extending theory building through the interactions between these theoretical perspectives. Third, we propose an integrative model of DAOs, exploring the interconnection between social material practices and interactions, human-machine agency, and institutional change with decentralized, automated, and autonomous principles. In doing so, we identify numerous promising research streams for future research agendas. In this article, we also examine the main business and ethical concerns regarding DAOs' societal and economic impacts, as well as the challenges of DAOs in avoiding unethical and illegal business activities.

Finally, the limitations of this research derive mostly from the adopted literature review methodology. The search-string technique based on database searches does not include contributions that are not published in academic journals. We attempted to address this by applying cross-referenced snowballing techniques to expand our original sample. However, we recognize that this snowballing might still suffer from a lack of randomized searches, subject to the selection bias of the scientific literature search. These limitations should be overcome by future research that adopts different methodologies and multidisciplinary research to expand both the sample and existing knowledge about DAOs. A particular focus should be on the impact of the nine research streams identified in this article, with empirical research and organizational case studies. We also encourage the combination of different streams.

CRedit authorship contribution statement

Carlos Santana: Literature review, data analysis, conceptual analysis, writing – original draft, review and editing.

Laura Albareda: Literature review, validation, conceptual analysis, writing – advanced draft, review and editing.

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Appendices. Supplementary data

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