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Toward a Formal Scholarly Understanding of Blockchain-Mediated Decentralization: A Systematic Review and a Framework

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This work analyses blockchain-mediated decentralization based on a systematic review of the scholarly understanding of the term 'decentralization' across multiple disciplines from computer to political sciences, examining how its various meanings are reflected in popular discourse on blockchains and distributed ledgers. The paper aims to capture the rigorous cross-domain understanding of decentralization and its most important features, and to map the commonalities and differences between it and some closely related concepts such as distribution, disintermediation and peer-to-peer (P2P). Across all domains, decentralization appears to be used as a solution to problems requiring non-trivial coordination across heterogeneous stakeholders. Blockchain-mediated decentralization appears to have unique characteristics reflecting an idiosyncratic set of authority-related values prevalent in so-called "crypto" online communities. Within blockchain space, the article argues against the binary positioning of "decentralization" and "centralization," proposing a dialectical approach and arguing that a system's authority allocation is a quality positioned on a spectrum between purely decentralized and completely centralized, noting how a blockchain set-up could simultaneously both have facets that are significantly centralized and others that are not. The authors document their systematic review findings and propose a framework for understanding blockchain-mediated decentralization, suggesting a definition, and outlining new directions for further human-centric research into distributed ledger technologies and for designing decentralized ecosystems.

Keywords: decentralization, decentralisation, blockchain, disintermediation, P2P

INTRODUCTION

Decentralization means the dispersion, delegation or distribution of power away from a central authority[1]. Blockchain is a type of computer-mediated socio-technical approach using distributed ledgers[2] to enable online transactions without apparent central authority. The main contribution of this paper is the analysis and organization of the unique meanings of decentralization from the perspective of scholars as well as blockchain users, developers and researchers, into a coherent framework, yielding a novel definition that encapsulates those meanings. The rationale for conducting this work is based on the fact that in the blockchain sphere, claims about decentralization have always been part and parcel of the debate on the value that that this technology promised to offer. However, the idiosyncrasies with which the term "decentralization" is used within the blockchain space have generated confusion, especially since computer science already had its long-standing discipline of distributed systems research, equipped with its own vocabulary that focuses on "distributed," rather than decentralized, technical set-ups. For instance, in the late 1990s, distributed computing enabled the push toward a peer-to-peer (P2P) mode of communication over Internet networks, also known as serverless communication, as it did not require a central server to facilitate most of its communication flows. With that in mind, a chiefly technological classification would categorize blockchains as a type of peer-to-peer and a serverless distributed system, without necessarily calling it a decentralized one, suggesting that the sources of meaning of "decentralization" in blockchain contexts are not necessarily technological in nature, thus motivating the need for the present effort.

Nevertheless, the debate in recent years, mostly on Medium, Twitter and other social media, has heavily centered around the notion of decentralization as the *raison d'être* for blockchains. Whilst the whitepaper specification for Bitcoin, the first-generation blockchain (Nakamoto, 2019) does not directly mention decentralization, it does still make the point that in this set-up, there would be "no central authority." The term "decentralization" is, however, explicitly mentioned in the description of the Ethereum blockchain[3], whose official description talks about "a global, decentralized platform for money and new kinds of applications." But then again, what is a decentralized platform exactly, and how is it different from a peer-to-peer one? And fundamentally, what sort of "authority" might such a decentralized platform be setting out to avoid, and what type of power is it dispersing? To answer these questions, and to clarify the meanings associated with "decentralization" in blockchain discourses, the paper first chronologically reviews the historical meanings of decentralization, and subsequently contributes a survey of the modern usage of the term, comparing the scholarly usage with the emerging use of the term in the blockchain sphere, also including gray literature.

The ultimate goal of this work is to add academic rigor into scholarly blockchain efforts, as rigorous approaches to blockchain research are notoriously scarce (Treiblmaier, 2019). Toward this end, our systematic review maps out cross-domain meanings of decentralization, then subsequently, a framework is proposed that enables the mapping of blockchain-mediated decentralization efforts into their more specific meanings. Finally, a resulting definition for "blockchain-mediated decentralization" is put forth by the authors. The dialectical thesis that this work will present posits that groups, communities and societies, in order to function, need to constantly coordinate complex match-making and decision-making processes that are networked (and increasingly online), and which can be coordinated through an optimal allocation of authority, on a continuum between "centralized" and "decentralized" power, with the aid of blockchain-mediated decentralization as one technique for improving existing set-ups within many contexts, including finance, governance and publishing.

RELATED WORK

To the best of the authors' knowledge, the present work embodies the first attempt at providing a framework for blockchain-mediated decentralization that would be rooted in the historical understanding of this concept. It should be noted that taxonomies do exist for classifying elements of decentralized systems, such as the one developed by Glaser and Bezzenberger (2015) which classifies cryptographic tokens, cryptocurrencies, decentralized organizations and decentralized applications; or the more recent framework developed by Tan (2019) which formalizes cryptographic token economics. However, these sort of technocentric frameworks would on balance tend to ignore the sociocultural reality from which blockchains have emerged, usually either focusing on the technical aspect of their implementation, or examining just their design, or just how they are applied within a narrow context. In contrast, the main scope of the present effort accentuates the archetypical nature of decentralization and how that archetype has informed and shaped the emergence of blockchain-mediated decentralization. Moreover, this work addresses the conclusions outlined in recent research by Schneider (2019) that urge for more specificity when discussing decentralization.

Historical Meanings of Decentralization

Despite plenty of evidence in the literature of the various meanings assigned to the term "decentralization" (Kim, 2008, pp. 4–7), it is safe to say that this term has always had its origins in political science. As early as the mid-1800s, Tocqueville already distinguished governance centralization from decentralization, the latter being a prerequisite for healthy democracy (Janara, 1998, p. 208). Tocqueville also claimed that whilst centralized governance brings about efficiency, it is *decentralization* that empowers the individual (p. 210). This notion has been

[1] Merriam-Webster.com Dictionary, s.v. "decentralization," accessed April 9, 2020, https://www.merriam-webster.com/dictionary/decentralization

[2] Whereas distributed ledgers existed before blockchains, and some researchers object to conflating distributed ledger technologies (DLT) with blockchains, recognizing that blockchains are just one member of the DLT umbrella, it has been noted that the two terms are widely used interchangeably in popular narratives (see, e.g.: r3.com/blockchain-101/)

[3] www.ethereum.org

echoed throughout centuries; for example, Tiebout (1956) believed that decentralization improves the provision of public goods, "increases variety," and addresses the needs of local populations; Seabright (1996) observed that decentralization increases accountability. Since the nineteenth century, competing definitions for decentralization have proliferated – from their survey of more than forty uses of this term, Dubois and Fattore (2009, pp. 707–711) found that decentralization usually focuses on themes of authority, responsibility, power and ownership, and that it often emphasizes the role of regional and local governments in politics and administration. Indeed, many countries have witnessed the rise of decentralization as a reaction to government failure, in an attempt to make their governments more accountable to individuals (Kim, 2008, p. 8). Thus, an initial glance at the literature points to the political science understanding of the term which focuses on addressing individual needs and preferences and individual empowerment. However, the role of technology in political decentralization requires a critical lens.

Almost in parallel to the political meaning of the word, in the last couple of decades, the term "decentralization" has made inroads into the world of computers and technological advancement. Curiously, a 1958 forecast in Harvard Business Review (Whisler and Leavitt, 1958) predicted that by the 1980s, the newly-emerging field of information technology would *re-centralize* the techniques of organizational management, leading to the increased concentration of power at the top, and the disappearance of the middle management. The authors predicted that the only remaining reasons for attempting managerial decentralization would be psychological in nature (as the authors put it, to make better use of "the whole man" by encouraging "active participation" rather than mechanistic work), whilst any major economic reasons for decentralization would have become obviated by emerging technology facilitating unprecedented efficiencies through concentrated power. These efficiencies were assumed to inevitably lead to the concentration of business insight in the hands of the select few top executives. It is particularly interesting how the psychological needs and preferences of the working population were downplayed by that narrative. The authors minimized the role of the human in the loop, as his/her agency increasingly becomes thwarted by prescriptive organizational processes and automated mechanisms.

However, by the end of the 1980s, and coinciding with the popularization of computer networks in the enterprise, the technological tide seemed to be turning against centralization. In Ensor (1988), Phil S. Ensor criticized the insular, inflexible top-down information flows in organizations and coined the term "functional silo syndrome" to mean a dysfunctional and unbending organizational structure; soon enough the talk of "silo mentality" commenced, and management consultancies began warning corporations against informational silos, encouraging individual departments to share insights. In the context of increasing demands for mechanisms and techniques promoting "variety and diversity" in manufacturing and services provision, it was Skolnikoff (1994) who concluded that "*technological change will tend, on balance, to favor decentralization of political power within societies over time.*" How much of this was wishful thinking is difficult to say due to the challenges in objectively measuring decentralization and political power, which will be discussed later in the article.

Meanwhile in counter-culture, the late 1980s and early 1990s witnessed the development of the cypherpunk movement (Assange et al., 2016) spreading the prophecy of the collapse of governments via technology (in particular, cryptographic technologies). The cypherpunk vision was defined in the Crypto Anarchist Manifesto, where Tim May (1992) famously stated that "*just as the technology of printing altered and reduced the power of medieval guilds and the social power structure, so too will cryptologic methods fundamentally alter the nature of corporations and of government interference in economic transactions.*" Hence, technology-mediated decentralization was no longer just limited to business and academia, it found its embodiment in a political movement. Many proponents of cypherpunk thought the cypherpunk ideal of a free society to be ultimately achievable through cryptography, the branch of mathematics and computing that deals with keeping one's individual preferences secret and enabling the private exchanging of communications in a way that could not be intercepted by governments and corporations. Cypherpunks, in particular believed that individual freedom requires active opposition to an emerging authoritarian and technocratic order (Beltramin, 2020), and this set of values and attitudes can, nowadays, also be observed in communities centered around blockchain and cryptocurrency development (the so-called "crypto" enthusiasts). However, despite the value attached to cryptography by cypherpunks and the "crypto" crowd, for many years, cryptography proved to be just one small facet of the efforts to counter authoritarianism, whilst there also emerged other non-cryptographic technologies attempting to empower the individual.

Modern Technology-Mediated Decentralization and Blockchains

Cryptographic methods enabled some small and medium-scale end-user solutions to the problem of preserving individual autonomy in cyberspace in the 1990s, such as PGP-encrypted emails and SSL-secured financial transactions in Web browsers, but they did not seem to facilitate any major form of political change. At the time, a tectonic political shift was about to be achieved by peer-to-peer technologies that did not heavily rely on encryption, but rather focused on the efficient routing of data between nodes in a network, without having to rely on a central server to coordinate the flows of information. A famous example of a peer-to-peer technology upsetting the centralized status quo was Napster at the turn of the millennium, a P2P application that took on the major labels, allowing anyone to freely download any music (and other types of content) that they wanted from their peers, albeit not legally. Inevitably, the big recording shops and artist rights' groups launched a stream of legal proceedings against Napster's creators[4], which led to the downfall of not just the Napster application but also

[4](e.g., *A&M Records, Inc. v. Napster, Inc.* and *Metallica v. Napster, Inc.*)

other alternative P2P solutions, with a social consequence of widespread stigma becoming attached to P2P usage.

What the P2P saga illustrated was that regulation had to play catch-up with technology and that pre-existing entrenched interests re-asserted their dominance through the political state apparatus. At the same time, the dramatic rise to power of large, consolidated technology providers including Google, Facebook and Amazon (dubbed the "Big Tech") placed Skolnikoff's hypothesis that "*technology favours decentralization*" under question, as well as putting to shame cypherpunk visions of the "collapse of governments." As recently as in the 2010s, researchers increasingly criticized the monopolistic and oligopolistic powers wielded by the centralized technology intermediaries, especially on the World Wide Web, which was originally designed to be universal and distributed. Some have called for the "re-decentralization" of the online space (Ibáñez et al., 2017) to try to rebalance the Web back to its Golden Age, if there ever was one. Blockchains/distributed ledgers have been embraced as the building block that would directly enable this re-decentralization. Fast forward to 2020, the contradictory claims about blockchain-mediated decentralization have generated a lot of confusion in the online, social media space, with widespread disagreement as to whether blockchains really render decentralization feasible.

To better understand blockchains (which are a subcategory of distributed ledger technologies, or DLTs, where records are shared by multiple participants), one should appreciate that these were initially designed with the following three goals in mind:

(1) To move away from centralized control of a ledger of transactions;
(2) To provide a tamper-proof synchronization mechanism for the above;
(3) To do the above among peers that do not necessarily trust each other or know each other.

Blockchain platforms, such as Bitcoin and Ethereum, keep permanent and unchangeable records of transactions (such as fund transfers) between multiple parties, whilst also enabling those parties to run smart contracts, which can be thought of as self-executing agreements that do not need a centralized third party to verify (Underwood, 2016). Within this setting, blockchains can provide a single version of the truth to everyone involved, making all sorts of agreements arguably easier to manage whilst producing a secure audit trail. Blockchains can also be used to model state machines, which makes them ideal for implementing control flows (workflows) consisting of multiple stages that need to be completed in a particular transaction (for example, check clearing or crowdfunding). Consequently, one can use a blockchain as a building block to provide decentralized services, such as a decentralized autonomous organization (DAO), a decentralized identity (DI), or decentralized finance (DeFi). On top of those building blocks, we see new decentralized ways of coordinating social undertakings. For example, a decentralized autonomous organization (DAO) is a form and technique for organizing financial and decision-making processes in a group of people bound by rules that are encoded as open-source smart contracts, where decisions are made democratically by stakeholders without relying on governmental or corporate coordination mechanisms (McGregor-Lowndes, 2019). The smart contracts coordinating the DAO's budget, membership and voting logic are all maintained on a blockchain.

However, DAOs suffer from a unique combination of governance issues due to a low barrier to entry and the difficulty in obtaining legal recourse in traditional courts. One major consideration is that it is not unreasonable for a minority stakeholder to be concerned that a majority might decide to liquidate the DAO and exclude minority stakeholders[5]. To avoid this scenario, a DAO needs constraint-imposing mechanisms, and ideally, a whole new dispute-resolution ecosystem that allows on-chain arbitration by default but also enables such a minority stakeholder to raise a dispute off-chain (e.g., in a traditional court of law) if necessary. To be able to implement this, DAOs must be defined in human-readable terms, and not just as computer code. Another point requiring attention is that if everyone in the DAO is following just their own personal incentives, the system risks degenerating. This is why some Web researchers have proposed that DAOs still need some form of top-down control in the form of "unincentivized incentivizers"[6] to strengthen their governance. The difficulty of achieving strong DAO governance has been illustrated by how DAOs have consistently received a lot of bad press due to abject governance failures, starting with the DAO Hack in June 2016 which saw millions of dollars stolen from Ethereum users by hackers exploiting smart contract vulnerabilities in the original Ethereum DAO. Even more recently, MakerDAO, which is also an Ethereum-based DAO, has been facing liquidation due to under-collateralization triggered by Ether volatility related to wider market volatility during the early 2020 financial crisis. At the time of writing this paper, MakerDAO was facing complete shutdown due to a lack of "crisis governance" processes which were never built into its governance design in the first place (Barrera, 2020) and this failure resulted in a long period of chaos among the participants of MakerDAO.

Nevertheless, DAOs present tremendous scope for innovation and experimentation. They can be used in tandem with decentralized identities (DI), which are currently under active research, but some proof-of-concept work is already being promoted by the Decentralized Identity Foundation (created by Microsoft, uPort Blockstack, Sovrin, and others), the goal of which is to establish a basic common framework for making claims about identities without the need for a central verifying authority. In such an approach, a decentralized identity is represented by its DID (Decentralized Identifier) that is linked to the public keys that are associated with it, and each such identity can be strongly associated with any public claims made by that identity online. DAOs and DIDs are examples of blockchain-based building blocks that can be used in decentralization initiatives, such as decentralized finance

[5]This is the proposition debated by Aragon: https://blog.aragon.one/proposal-agreements-and-the-aragon-court/

[6]Scott Alexander's "Meditations on Moloch": https://slatestarcodex.com/2014/07/30/meditations-on-moloch/

("DeFi"). A robust online financial ecosystem based on the blockchain has now evolved, in which one can find blockchain-based financial intermediaries ranging from decentralized exchanges to "algorithmic central banks." Given the variety of technological propositions on offer that claim to be decentralized, from identity to finance, is blockchain really a viable vehicle for decentralization, and if so, then what sort of decentralization is it? Knowing that it was the loss of *trust* in centralized entities that gave birth to blockchain in the first place, it is to be expected that blockchain decentralization will not be purely technological in scope, but rather human-centric, transforming psycho-social aspects related to trust, identity management and user experience (Gaggioli et al., 2019).

THE SYSTEMATIC REVIEW

Methodology

This part of the present contribution advances the understanding of blockchain decentralization discourses by providing the meanings of decentralization in general scholarly discourses and comparing them to the usages of the word within the context of blockchain-related papers. A literature review was performed based on the systematic approach similar to the Systematic Literature Review (SLR) as outlined by Kitchenham et al. (2010). The SLR research question hereby was *"what contexts, meanings and sentiments have been historically ascribed to decentralization by the authors of highly influential publications?"* To best assist with answering this question, the data source of choice was the Web of Science set of databases hosted by Clarivate Analytics, which was queried using its Web portal (http://webofknowledge.com) in order to carry out citation analysis and to complete the systematic analysis on the most influential articles. The alternative would have been Google Scholar, which several academics have been critical of Jacsó (2006) on grounds of poor sourcing quality and incorrect citations. Web of Science was ultimately elected due to its accuracy and the higher level of reproducibility that it facilitated.

The search results were manually inspected, and papers were read by the researchers to build a relevant understanding. The review technique relied on analyzing the sentiments, meanings and themes associated with the usage of decentralization across most influential scholarly articles. Only those articles became considered where "*decentralization*" (or "*decentralisation*") was mentioned explicitly in the title, abstract or keywords, or where there was an attempt to provide a definition for it in the body of the paper. If "decentralization" was contained in the body of the article but explicitly missing from the abstract, the abstract was screened for the inclusion of a related term, such as "centralization," "decentralizing," etc. (i.e., the declination of "decentralization" or "centralization"). Only articles with at least one citation were considered. More than 4000 articles were screened for this purpose. The findings were compiled into the relevant tables in this paper. Secondly, the same approach was repeated whilst additionally searching for blockchain as one of the required keywords.

For the first task, the initial search query was "(*decentralization* ***OR*** *decentralisation*) ***NOT*** *blockchain*" and the source was all Web of Science databases. For the second task, the initial search query was "(*decentralization* ***OR*** *decentralisation*) ***AND*** *blockchain*" and the source was, like before, all databases included in Web of Science. The choice of the two Boolean expressions, yielding disjoint sets of papers, was motivated by the need to focus on decentralization primarily, and blockchain secondarily, and to speed up the filtering process because of the vast number of articles mentioning decentralization. The authors also made their choice to disregard articles just mentioning blockchains but not discussing decentralization, as they were deemed as not relevant to the systematic review question[7]. The review was followed by an analysis and inclusion of additional sources beyond the scholarly ones. Furthermore, if lower-citation articles were found to contain a repeated combination of context/meaning/sentiment that was identical to a previously-found higher-citation article, then only the higher-citation article would have been included in our reported results, to maintain the conciseness of our findings.

Limitations

One limitation associated with this methodology is that search reproducibility is limited by the subjectivity of discarding articles that mentioned decentralization too briefly without making a case for it, or without defining it, as these aspects were subjectively evaluated and decided upon manual inspection and screening by a human researcher. This human-based evaluation approach also poses a limitation in how the sentiments (positive, negative, or neutral) were subjectively decided based on the double-hermeneutic, i.e., the researcher's individual interpretation of the context and how it was evaluated by previous researchers. Finally, using Web of Science may limit the researchers' visibility of the most recent search results given the length of the academic cycle required to publish and for the work to be indexed, in which case using Google Scholar would have presented some advantages due to Scholar's broader inclusivity of the more recent scholarly efforts as well as pre-prints and gray literature.

Results

The most influential (in terms of citations) mentions of decentralization across all non-blockchain scholarly domains are provided in **Table 1**. These results are sorted by citation counts in descending order. For each mention, the table provides the overall sentiment toward decentralization (negative signified by the minus sign ("−"), positive as the plus sign ("++"), or broadly neutral as "+/−"), as well as the meaning/perspective and themes/findings for that particular usage. **Table 1** was cut off arbitrarily at 26 items for scoping reasons and due to the fact that many themes in less-cited items tended to mimic the themes in the more-cited items. **Table 2** provides the same style of an overview but is specifically restricted to the blockchain context. This table was cut off arbitrarily at 16 items due to

[7]"What contexts, meanings and sentiments have been historically ascribed to decentralization by authors of highly influential publications."

TABLE 1 | Most relevant mentions of decentralization across non-blockchain contexts ordered by citation counts.

Context category	Citations	Sentiment	Meaning/perspective	Themes/findings	References
Governance	1009	+	Optimal allocation of authority	Multi-level governance, accommodating diversity, second-order coordination, "how" vs. "for whom"	Hooghe and Marks, 2003
Health administration	877	+	Fiscal (expenditure/revenue) and administrative reform	Political redesign, transferring responsibility through policy and frameworks, allowing more stakeholders to take part in decision-making processes	Paim et al., 2011
Health administration	607	+/−	A trade-off in ensuring healthcare quality	A multilevel approach to change; groups, teams and microsystems	Ferlie and Shortell, 2001
Governance	251	+	Allocation of control rights under incomplete contracts	Determining levels of fiscal transfers between localities; preventing governments from appropriating resources	Seabright, 1996
Environmental governance	642	+	Shift away from centralized form of governance	Loss of faith in the state as a custodian of nature; community-based management, hybrid forms of governance	Lemos and Agrawal, 2006
Business management	628	+/−	Decentralization merely means that concentrated authority is delegated	Delegated authority can also be recentralized; organizations often go through these pendulum swings but both ends of the spectrum are simply different manifestations of concentrated authority	Zuboff and Maxmin, 2004
Governance	536	−	Decentralization refers to both a state and a process	Decentralization can increase disparities, jeopardize stability, undermine efficiency	Prud'Homme, 1995
Governance	522	+	Decentralization = major governance reform/major institutional framework	Making governance more responsive to the "felt needs" of the population, introducing checks-and-balances, technology makes it easier to provide public services	Bardhan, 2002
Societal structure	477	+/−	Decentralized systems are flexible, networked forms of power	Networked power structures are superior to top-down chains, the state tries to regain legitimacy by decentralizing responsibilities and resources	Castells, 2000
Fiscal governance	427	+	Decentralization means fiscal decentralization (shifting fiscal responsibility downwards)	Estimates suggest that fiscal decentralization in government expenditure is strongly and significantly associated with lower corruption	Fisman and Gatti, 2002
Fiscal governance	400	+/−	Decentralization is not about fiscal decentralization itself, but what form does it take; paradoxically, decentralization may require a strong central government to be effective	It is difficult for a central authority to determine the particular preferences of the residents in the myriad of decentralized jurisdictions; there exists an asymmetry of information: local governments know the preferences of their residents, but the central government does not	Oates, 2005
Social aspects of computing	379	+	Decentralization is P2P; it is community driven and depends on distributed data and distributed indexing	Decentralization enhances fault tolerance and security, but it may make regulation of the content almost impossible	Parameswaran et al., 2001
Social aspects of computing	304	+/−	Decentralization is never complete as there is continuous struggle between the forces of centralization and decentralization	This struggle can help blurring the boundary between man and machine, and embrace social computing in which humans are part of the computation and decision-making loop, resulting in a human-centered system design	Garcia Lopez et al., 2015

(Continued)

TABLE 1 | Continued

Context category	Citations	Sentiment	Meaning/perspective	Themes/findings	References
Environmental governance	284	–	Decentralization proponents are too infatuated with the local sphere	International central organizations have a critical role to play in natural resource governance	Andersson and Ostrom, 2008
Complex systems	271	+	Decentralization overcomes specific difficulties arising in large-scale complex systems	Decentralization as decomposition improves robustness by minimizing delays and structural constraints under uncertainty	Bakule, 2008
Fiscal governance	261	+/–	Decentralization is fiscal decentralization	Fiscal decentralization hampers growth in developing countries, but doesn't have that effect in developed countries	Davoodi and Zou, 1998
Social aspects of computing	255	+/–	Models of decentralization follow from the limited capacities of individuals for information processing and decision making	Hierarchical structures, which are often thought of central structures, are actually effective in decentralizing the activities of information processing	Radner, 1993
Conflict and tribalism	227	+/–	Decentralization can reduce conflict in some countries	Decentralization may increase conflict indirectly by encouraging growth of regional parties	Brancati, 2006
Marketing	189	+	Decentralization is a Nash equilibrium strategy	Strategic interaction is a prerequisite to decentralization being profitable	Moorthy, 1988
Logistics management	180	+	Decentralization means decentralized production	Decentralized decision-making / self-regulation; human beings, machines and resources communicate with each other as naturally as in a social network	Hofmann and Rüsch, 2017
Governance	165	+/–	Decentralization means devolution or the transfer of power to lower levels	Authority requires legitimacy; decentralization of resources is different from decentralization of authority	Rodríguez-Pose and Gill, 2002
Urban planning and transport	143	–	Urban decentralization as a settlement pattern	Decentralization influences planning controls for public transport	Schwanen et al., 2004
Environmental governance	123	+	Transferring power through decentralization requires coordination, civic education campaigns	Chicken-and-egg problem; decentralization requires a critical mass to decentralize; broad resistance of central governments to local democratization and decentralization of power; what's required is applying multiple accountability measures, in addition to elections, to support democratic local institutions; decentralization requires critical analysis and informed public debate	Ribot, 2003
Social aspects of computing	88	+/–	Economic factors dictate whether to centralize or decentralize computing	Politics of organization and resources shape the debate, centering on the issue of control; a universally appropriate arrangement has never been found	King, 1983
Meta-analysis	87	+	Decentralization means elected local governments	Decentralization addresses the disarticulations created by globalization; economic discourse of decentralization has emerged as a central justification for the decentralization of power,	Rodríguez-Pose and Sandall, 2008
Meta-analysis	54	+/–	Technocratic decentralization appears to create disorder, consolidates authoritarian politics and predatory economic relationships	Decentralization did not change the basic frameworks of power which remain intact; market reforms have been resisted and hijacked to consolidate predatory state and private oligarchies; the factors of transparency and accountability, and other aspects of "good governance," are no more inherent within decentralized government than centralized government; power reforms need to be enforced through political struggle	Hadiz, 2010

TABLE 2 | Top 16 relevant mentions of decentralization in blockchain contexts.

Context title	Citaions	Sentiment	Meaning/perspective	Themes/findings	References
Blockchain technology and decentralized governance: Is the state still necessary?	278	+/−	Decentralization of government services through *permissioned* blockchains is possible and desirable; decentralization is advocated by individuals and groups that fail to see the value-adding contribution of centralized institutions and the State in particular, seeing governments as "too slow, to corrupt, too lacking in innovation and benefiting too few; "blockchain-based governance" is the final stage of decentralization	Blockchain enables decentralized domain names, decentralized voting for tamper-proof ballots, decentralized autonomous organizations/corporations/societies (DAOs, DACs, DASs), and the disintermediation of all transactions on a global basis; potentially allows humans to redesign their interactions in politics; decentralization enhances "deliberative democracy"; decentralization plays a role in "multi-stakeholder" and "collaborative" governance; current state of blockchain decentralization is *pre-political* because it does not solve conflicts; decentralized platforms still have a tendency to elitism and centralization	Atzori, 2015
Blockchain disruption and smart contracts	215	+	Decentralization means the dispersed keeping and verification of records in a public information distribution setting	Decentralization relates to consensus quality; the features of blockchain remold the landscape of competition; blockchains sustain new market equilibria with a wider range of economic outcomes	Cong and He, 2019
Pervasive decentralization of digital infrastructures: a framework for blockchain enabled system and use case analysis	201	+/−	Technological decentralization is a driving force in the ongoing evolution and increasing openness of digital infrastructures and services	Decentralized blockchain systems could replace platform providers underlying all market models	Glaser, 2017
An overview of blockchain technology: architecture, consensus, and future trends	188	+	Decentralization means the removal of the central trusted agency such as the central banking authority	Consensus algorithms are used to manage data consistency required for decentralization, without a trusted third party	Zheng et al., 2018
decentralized applications: harnessing Bitcoin's blockchain technology	165	+	Decentralization of transactions requires decentralization of applications	Decentralized applications (dApps) require open-source code, cryptocurrency support, decentralized consensus and transparency with no single point of failure	Raval, 2016
The invisible politics of Bitcoin: governance crisis of a decentralized infrastructure	109	−	Decentralization requires peer-to-peer architectures	The conception of Bitcoin as a decentralized platform was compromised by social and cultural factors; even a decentralized technology designed to promote disintermediation is unable to protect itself from capitalist tendencies to concentrate power and wealth; Bitcoin has centralized governance and oligopolistic market structure; technocratic power structure should be replaced with an institutional framework	de Filippi and Loveluck, 2014
Governance in blockchain technologies and social contract theories	93	+/−	Blockchain decentralization has anarchist and libertarian roots; centralized powers like states and banks are easily corrupted; blockchain lets individuals create self-governing communities with enforceable rules without any centralized (hierarchical) power	Blockchain technology is not politically neutral, but transformative; political implications of blockchain are significant; decentralization requires governance; blockchain contracting offers "veil of ignorance" but lacks the idea of "common good" and distributive justice; modeling governance on the blockchain and how to govern the blockchain itself requires further research in political philosophy	Reijers et al., 2016
Blockchain solutions for big data challenges a literature review	34	+	Decentralization requires decentralized trust which is the consensus of nodes	Decentralized trust means the opposite of client-server architecture	Karafiloski and Mishev, 2017

(Continued)

TABLE 2 | Continued

Context title	Citaions	Sentiment	Meaning/perspective	Themes/findings	References
Redecentralizing the web with distributed ledgers	20	+	Two axes of decentralization: architectural and application decentralization	Distributed ledgers will continue to support decentralized communities with different needs of privacy, verifiability and trust	Ibáñez et al., 2017
A critical review of blockchain and its current applications	10	+/−	Decentralized means distributed	Decentralization means the distribution of markets, money and payments	Adhi Tama et al., 2017
Blockchain: the birth of decentralized governance	4	+/−	Decentralization can protect individuals but also hinders coordination	New forms of "soft" decentralized governance (anarchic, aristocratic, democratic and autocratic) are required to avoid bad equilibria	Arruñada and Garicano, 2018
Collusion by blockchain and smart contracts	2	+/−	Decentralization requires decentralized regulatory mechanisms	Blockchain decentralization complicates the work of antitrust and competition agencies	Schrepel, 2019
Scholarly publishing on the blockchain–from smart papers to smart informetrics	2	+	A decentralized environment is an alternative to centralized publishing houses and large technology providers	Decentralization allows authors to retain the ownership of, and sovereignty over their data, and for others to calculate trustworthy computations of analytics that do not rely on any centralized data aggregator	Hoffman et al., 2019
Deconstructing "Decentralization": Exploring the Core Claim of Crypto Systems	1	−	"Decentralization" functions as a liability shield for those operating the blockchains	The "veil of decentralization" leads to the misunderstanding of the power dynamics within blockchain systems, and faulty risk assessments	Walch, 2019
Web 3.0: the decentralized web, blockchain networks and protocol innovation	1	+/−	Decentralization is about connecting people	The development of the decentralized web is focused on developing protocols that may not be noticed by end users	Alabdulwahhab, 2018
Decentralization: an incomplete ambition	0	+/−	The rhetoric of decentralization diverts focus from where "concentrations of power" are operating	For decentralization to be useful in formulating future social orders, it needs to become a much more specific concept	Schneider, 2019

the lack of high-quality blockchain research attributable to the nascent nature of the field.

The data in both tables suggests that decentralization is seen as something mildly positive and neutral, rather than negative. Across scholarly domains (**Table 1**), the term "decentralization" has 12/26 (46%) positive meanings, 11/26 (42%) neutral and 3/26 (12%) negative. In blockchain contexts (**Table 2**) the sentiment associated with decentralization is positive in 6/16 (38%) cases, neutral 8/16 (50%) and negative in 2/16 (12%) cases. Within non-blockchain contexts (**Table 1**), the term "decentralization" is mostly used in the category of **governance** (5 research items), **social aspects of computing** (4 items), **environmental governance** (3 items), **fiscal governance** (3 items), **health administration** (2 items), **societal structure** (1 item), **conflict and tribalism** (1 item), **urban planning and transport** (1 item), **logistics** (1), **marketing** (1), **complex systems** (1), **business management** (1) and in meta-analyses (2 items).

Having additionally analyzed gray literature on decentralizing the Web, it is evident that the communities enthusiastic about the adoption and development of blockchains and cryptocurrencies (called "crypto" for short) use the phrase "Web 3" ("Web3," "Web 3.0") in a way that is fundamentally different to academia, as noted by Alabdulwahhab (2018), where academia describes the next iteration of the World Wide Web as a semantic web built on RDF and SPARQL, whilst crypto enthusiasts perceive the next Web to be a decentralized system built with blockchains, zero-trust protocols and distributed secret management running on top of P2P infrastructures (see, for example, the "Web 3.0 Technology Stack" online schematic[8]). One could, however, imagine a new Web making use of both semantic as well as distributed-ledger technologies (potentially drawing concepts from The Graph[9], which is a decentralized protocol for indexing and querying linked data from blockchains using open APIs), and this would be less of a technological challenge than it would be a social one, requiring the coming together of disjointed communities with different sets of values.

DISCUSSION – HOW IS BLOCKCHAIN-MEDIATED DECENTRALIZATION UNIQUE?

Based on the results reported above, decentralization is portrayed in scholarly contexts as either an end-state, or a living process, depending on the framing of the decentralization problem. One of the most influential articles from **Table 1** (Hooghe and Marks, 2003) defines the meaning of the problem as optimal

[8]web3.foundation/about

[9]https://thegraph.com/docs/introduction#what-the-graph-is

allocation of authority, suggesting that between a fully central and fully dispersed authority, there must exist some sort of optimum, thus reframing decentralization as an optimization technique. The paper also dubs it a second-order coordination problem because it involves coordinating the coordinators, i.e., the institutions that govern our everyday lives. This has some similarities to Bakule's (2008) view that decentralization enables independent decision processes and improves the robustness of a complex system. Hooghe and Marks (2003), however, conclude that decentralization should always happen for someone, i.e., to empower an individual or a group of individuals, and that the focus should be on the "for whom" rather than "how." It is, therefore, the human-centric approach that sets their view apart.

In the world of blockchain, the focus has been often on the "how" instead of "for whom," as upon inspection of the 13 research items listed in **Table 2**, only two articles attempt to define (let alone exhaustively model) the relevant stakeholders that could potentially benefit from decentralization (Atzori, 2015; Hoffman et al., 2019). Across the remaining articles, the "how" of blockchain decentralization appears to most commonly rely on cutting out the middleman, a process known as "disintermediation." By removing the need for traditional, centralized and trusted third-parties such as financial intermediaries required to complete monetary transactions, blockchain technology has been allowing collaborative transfers of value and information directly between transacting parties, thus disintermediating online transactions. However, to the multi-layered nature of the Internet, network decentralization of communications and even individual transactions does not necessarily lead to disintermediation of services associated with peer-to-peer value exchange. Therefore, the re-emergence of "decentralized intermediaries" acting as gatekeepers of decentralized networks is a threat, in that it may introduce unwarranted complexity without providing a clear benefit to end users of those networks. We have recently seen closed-source crypto exchanges appear, which is an example of non-disintermediated (siloed) decentralization that replicates the power dynamics of centralized financial houses, where trust is brokered by special third parties that may quickly gain a potentially unfair advantage over other players in the market. The above shows that the "selling point" of blockchain decentralization comes with a *caveat emptor* that care should be taken to define the relevant stakeholders and their interactions, not just within a single blockchain smart contract, but across the broader ecosystem, identifying risks associated with the second-system effect of re-centralization.

Even if the underlying blockchain is a mixture of decentralized and centralized elements, decentralization is still seen as the *unique selling proposition* of blockchains. One of the most cited blockchain texts in **Table 2** (Zheng et al., 2018) portrayed decentralization as the removal of a central trusted agency such as the central bank. Hence, the importance of the financial system in decentralization discourses is not to be understated. The Bitcoin blockchain that launched in 2009 published its very first block (the "genesis" block) with a hard-coded reference to *The Times* January 2009 headline announcing the bailout of the big banks by the British government, the all-too-obvious critique of the failing economic system. This highly centralized financial system, resuscitated by the also highly centralized state/monetary apparatus, had to be artificially propped up with the taxpayer's money, beginning an era of austerity policies that dispossessed the poorest and "*the demise of the post-war social contract which had helped flatten gross inequities in income distribution*" (Labonté, 2012). Against that grim backdrop, blockchains and smart contracts seemed to offer a technological solution to a problem of failing social governance, failing social justice and the failing social contract. Was cipher-punk ideology about to make a great comeback thanks to Bitcoin? There is currently not enough data to suggest that this could be the case, which is one of the reasons why recent research has been somewhat skeptical of the value added by blockchains for the individual.

Some authors go as far as suggesting that blockchain decentralization is not all that it is portrayed to be. In "*Deconstructing decentralization*," Walch (2019) argued that the word decentralization is used in blockchain discourse to describe distributed systems that "are resilient and lack concentrated power centers." The scholar identified the distinct sources of the meaning of decentralization as coming from: law, political theory, computer science and networks theory, yielding various interpretations of the word. Of utmost importance is the observation that decentralization is not just elusive, as if a moving target, but also lies on a spectrum rather than being binary, echoing the findings from Atzori (2015) – that decentralized platforms still have a tendency toward elitism and secondary centralization – as well as de Filippi and Loveluck (2014) that blockchain-mediated decentralization is unable to resist the opposing forces that tend to centralize power. From an ethical angle, Walch (2019) assumed that there exists a moral risk that she called a "*veil of decentralization*," explained as a theoretical side-effect that allows accountability to diminish in a seemingly decentralized system.

Walch's veil of decentralization appears to be closely related to the Twitter catch-phrase "*decentralization theater*"[10], an expression of disillusionment, and a phenomenon that has been witnessed in platforms and systems that still had a central authority, albeit a hidden one, just as in the case of Ethereum's original implementation where some of its transactions were rolled back due to the intervention by its creator, Vitalik Buterin; or similarly the IOTA blockchain, which recently has been "paused" by its core organization due to security concerns, preventing users from transacting on it and generating a lot of discontent on social media such as Twitter. The misleading nature of the decentralization theater is most likely caused by the fact that there is currently no clear-cut definition of what a "*decentralized platform*" is, no consensus over how decentralization should be understood in the context of blockchain, and a lack of agreement on what blockchain decentralization achieves or sets out to achieve. A case in point is "collusion by blockchains and smart contracts," as reported by Cong and He (2019) and Schrepel (2019), whereby federated blockchains were construed

[10]See, for example, this tweet by Emin Gün Sirer: https://twitter.com/el33th4xor/status/1177208765084553216

to facilitate collusion through cartel-enabling smart contracts hampering deconcentration efforts of antitrust and competition agencies. de Filippi and Loveluck (2014) are equally cautious of recommending blockchains for decentralization purposes, observing that the conception of Bitcoin as a decentralized platform was compromised by its inability to protect itself from capitalist tendencies to concentrate power and wealth. The researchers claimed that Bitcoin has centralized governance and oligopolistic market structure, suggesting that its technocratic power structure should be replaced with an institutional (and more centralized) framework.

Nevertheless, post-Bitcoin blockchains may be more useful in driving meaningful sociotechnical decentralization than Bitcoin ever was. For example, Hoffman et al. (2019) showed how public Ethereum-driven decentralization allows authors and creators to retain the ownership of, and sovereignty over their data, and for others to calculate trustworthy computations of analytics (such as bibliometrics) that do not rely on any "big shop" centralized data aggregator. Further on the topic of public blockchains, Raval (2016) showed how they can be used to create distributed applications such as clones of social media and marketplaces with decentralized governance and increased transparency. Having analyzed many more blockchain use-cases and having carried out an extensive literature review with exhaustive discourse analysis, Atzori (2015) concluded that it is federated (permissioned) blockchains, and not purely public blockchains, that may be useful and desirable decentralized tools for building the "political compromise," i.e., reconciling tensions between individual interests and the public good, yielding optimal allocation of authority. Nevertheless, the author warned against the risk of neoliberal corporate agendas producing its own dystopian version of algorithm-based "decentralized society" akin to an oppressive state that uses blockchains to modify the existing balance of power and undermine individual rights. Therefore, the researcher called for a "mature and interdisciplinary" approach to assess the benefits and risks of blockchain-mediated decentralization. However, such an objective discussion on blockchain decentralization is still particularly challenging due to methodological issues which will be discussed in the next subsection.

MEASURING AND INTERPRETING BLOCKCHAIN-MEDIATED DECENTRALIZATION

Despite the importance of the centralization-decentralization continuum (defined as the optimal allocation of authority in the "political compromise" outlined by Atzori, 2015), most examples of the discourse on this topic lack agreed-upon metrics and are therefore devoid of proper quantification. To measure the degree of the decentralization of power it is necessary that one first quantifies this power and analyze its distribution, both of which are complex tasks and not easy to achieve as researchers usually focus only on specific facets of decentralization whilst ignoring its other aspects (Pina Sanchez, 2014, p. 12). Since decentralization is not only defined but also described and measured in a plethora of ways, this methodological hurdle contributes to inconsistent research outcomes (Sharma, 2006, pp. 53, 55). Outside of the blockchain context and to build a working definition of technological centralization and decentralization, King (1983) introduces three decentralized dimensions that have to be measured – the locus of decision making (is it concentrated in one person, a small group, or rather dispersed across various levels), the placement of facilities (are the facilities in one place or spread around), and the locus of function (operations), observing that there is no universal "best" solution and that each organization has to find its unique mix of parameters. In the context of blockchain, there are a couple of issues with transplanting King's framework, the key issue being that the approach is not a technologically-oriented one. Another problem with King's framework's applicability to blockchain is that the author assumed a level of tangibility of "*facilities*," the meaning of which appears elusive in the current era of cloud computing, whereby IT facilities are now both global and on-demand. One other, similar, criticism would be the immateriality of the locus of operations in today's era of globalization, given that the largest corporations are not taxed locally, and their operations cannot be easily traced to particular geographical locations. It can be, therefore, argued that a more viable blockchain decentralization framework should be simpler, mostly focusing on the locus of decision making, to measure the bargaining power of the individual in their personal self-determination. It is not particularly surprising to note that no such framework exists as of yet.

Nevertheless, some very specific metrics in the blockchain space have been introduced to measure blockchain decentralization. In their online post, the authors Srinivasan and Lee (2017), propose the minimum Nakamoto coefficient as a simple, quantitative measure of a system's decentralization inspired by the Gini coefficient. The metric focuses on the size of each of the network's subsystems, and in the case of Bitcoin, these are the clients, developers, miners, exchanges, nodes and accounts. If any of these six subsystems becomes unreasonably centralized, the total metric will reflect that centralization. As the minimum Nakamoto coefficient increases, the minimum number of actors required to compromise the whole system thus also increases. Looking at decentralization metrics from an analytics angle, the founder of Dogecoin, Jackson Palmer, created the AreWeDecentralizedYet.com (AWDY) website. The AWDY website lists in real time, and for each major blockchain, the values for the following metrics:

(1) The number of client codebases that account for 90% of nodes;
(2) The number of entities in control of more than half of total mining power;
(3) The number of public nodes;
(4) The amount of money supply held by top 100 accounts.

If the Web data published by AWDY is to be trusted, major blockchains appear to be highly centralized, often in more than just one respect, failing to live up to their decentralization aspirations and their social media claims promoting the "veil"

of decentralization. For example, just four Bitcoin mining pools comprise more than 50% mining power of the blockchain. Meanwhile in Ethereum, approximately one-third of the total money supply is in the hands of top 100 stakeholders. The above examples illustrate that it is an important responsibility for blockchain developers and researchers to regularly monitor, report and reflect upon these diverse metrics reflecting the reality of the decentralized/centralized spectrum, and to gauge whether any trends are present or emerge in the long term. More discussion, involving new emerging scholarly discourses, should be based on the nascent blockchain decentralization metrics to counter the decentralization hype which is often spread on social media without any facts to back up common blockchain "decentralization" claims.

Even though we have just shown that decentralization can be measured in numerous ways, understanding decentralization is not merely a quantitative problem. As a social construct, it is qualitative and subtle, meaning that one must be mindful not just of the different metrics, but also of the different interpretations thereof. Zuboff and Maxmin (2004) point out that the "false" dichotomy of centralization and decentralization should not be confused with the fundamental problem of opposing concentrated authority inherent to the hierarchical managerial structure of the capitalist firm which has its origins in concentration. They posit that any quantitative measuring of "decentralization" could be a red herring, simply resolving the level of *delegation* of concentrated authority, without any consideration given to the breaking up of that concentration on a more essential level. The authors propose that instead of simple decentralization, stepping beyond the constraints and limitations of managerial capitalism would need to involve a more fundamental shift in enterprise logic through the creation of a new paradigm. With that in mind, they propose a framework of "*distributed capitalism*" where individuals are recognized as the source of all value and all cash flow. Because value is distributed and lodged in individuals, what this necessitates is distributed production, distributed ownership and distributed control. Even though Zuboff and Maxmin wrote their pivotal work a couple of years before first blockchains emerged, the so-called "*federated support networks*" proposed by them are organized in a way that can link enterprises under "distributed capitalism" in a manner "providing unique aggregations of products and services" whilst benefiting from the fact that "infrastructure convergence dramatically lowers operating costs and working capital," all of which is essentially describing an archetypical structure similar to that of a blockchain-based ecosystem. This finding enables us to see a bit more clearly that blockchain is not just a product of its technology, it is a product of its modern times, deeply enmeshed in the social and economic reality of "the times of decentralization," which is another way of describing the post-cypherpunk era. Having discussed the different interpretations and measures of blockchain-mediated decentralization, in the final chapters of this work, the authors will attempt to merge the ideas from the social and technical realms to propose a decentralization framework and a definition based on blockchains.

Toward a Decentralization Framework With Blockchains

Anfara and Mertz (2014) define a theoretical framework as any empirical theory of social processes that can be applied to gain an understanding of a phenomenon. The extensive systematic review reported earlier in this work suggested that a framework for blockchain decentralization does not currently exist. The present paper has, thus far, provided a theoretical reflection on the meanings and understandings of the concepts of decentralization across scholarly and blockchain-related contexts, revealing decentralization as a multifaceted concept with several dimensions. Based on the discussion above, one may envision a tentative framework which will help the future researcher direct their focus in their future work by breaking down decentralization into its dimensions and examining which ones can be tackled by means of blockchains and smart contracts. The main mechanism for gaining that focus is through clarifying the relative importance and meaning of technological, social, political and administrative imperatives and incentives, which can be achieved by answering the following questions: ***what is being decentralized and why*** (the case for decentralization), and ***how much of it are we going to decentralize and how will blockchains help*** (the scope and the action plan for decentralization with blockchains). The resultant framework is represented visually as a workflow in **Figure 1** and the individual steps are then discussed in sections "Problem Definition and Establishing the Case for Blockchain Decentralization," "Defining the Scope of Blockchain Decentralization," and "How Are We Decentralizing With Blockchains?"

Problem Definition and Establishing the Case for Blockchain Decentralization

The "what" and "why" questions are the most essential ones to answer, so as to avoid an incorrectly designed proposal that does not address any issue in particular, which can be described as a "*solution looking for a problem*"[11]. There are, in fact, many good reasons for decentralizing the status quo with blockchains, for example, to improve the bargaining power of the end-users of traditionally-provided financial services, whole marketplaces, and cloud-based IT applications. This is because most centralized socio-economic institutions and systems such as governments, banks and corporations, may share one or more negative issues with the way in which they handle, store, process, share and give access to individuals' data records. These issues can involve a perceived loss of control by the individual (low bargaining power, feeling of exploitation), loss of trust, unnecessary complexity (bureaucracy, overhead), vulnerability (security breaches), inefficiency (slowness and unresponsiveness), perceived injustice (unwarranted profits, lack of redistributive efforts), opaqueness (lack of transparency and accountability), as well as a propensity to corruption (decay and degradation of service quality), which are the themes identified across **Tables 1**, **2**.

[11] "*Too many projects started with the technology rather than the solution*": Blockchain: disillusionment descends on financial services, Financial Times, 24/09/19: https://www.ft.com/content/93140eac-9cbb-11e9-9c06-a4640c9feebb

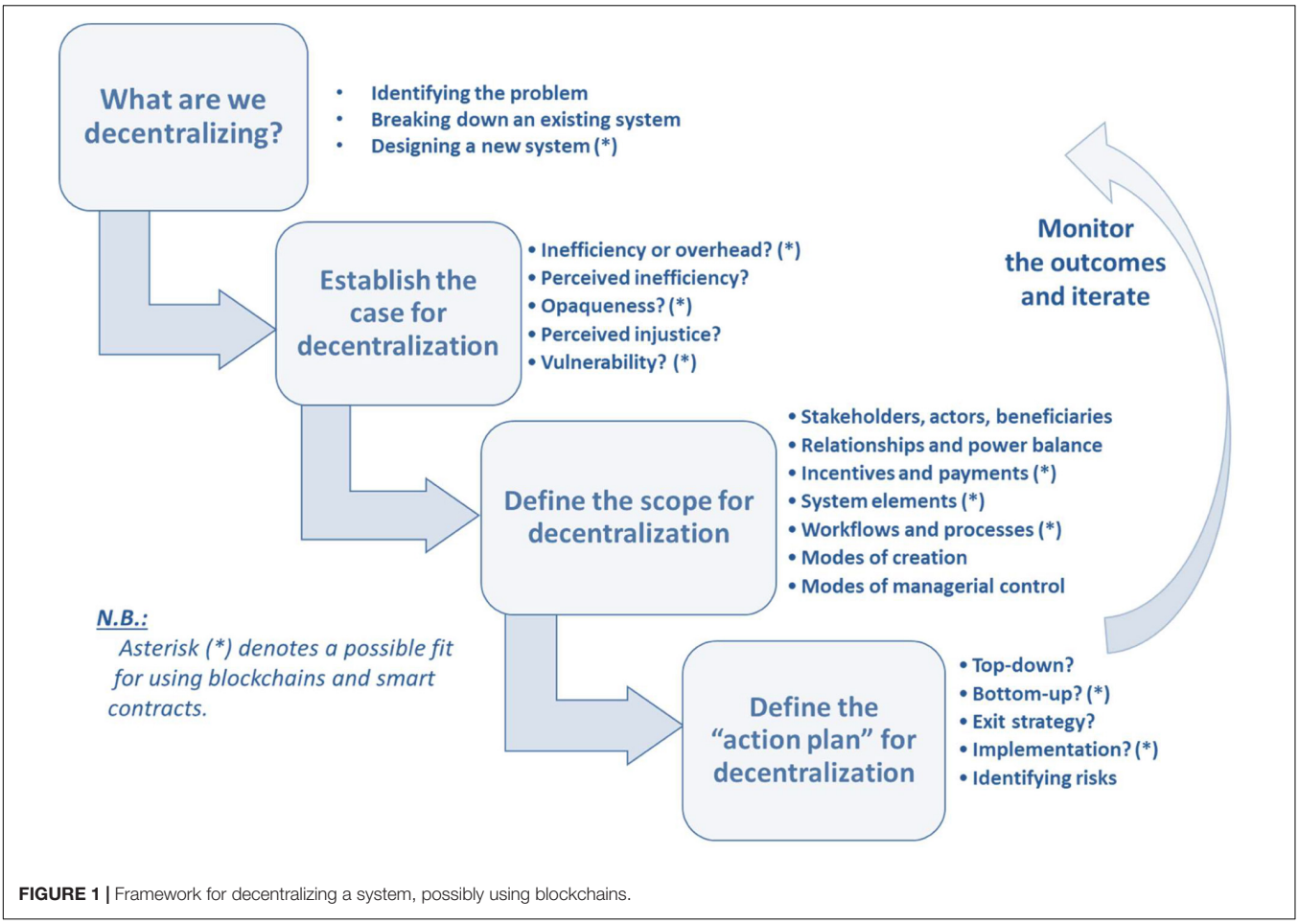

FIGURE 1 | Framework for decentralizing a system, possibly using blockchains.

As each institution is different in terms of size, purpose and structure, and the issues outlined above may manifest themselves differently under different scenarios, it is essential that the researcher first defines which issue it is exactly that is being tackled, which should point them at the most suitable course of action. For example, when tackling a market complexity issue, we may want to "decentralize" the market to improve the coordination between the different stakeholders to better enable them to match their preferences to the options that are available to them. Opaqueness, in turn, calls for an increase in the transparency and availability of the data flows, such as a provision of user-friendly search and indexing functionalities for reviewing live transactional data and historical audit trails. However, institutional opaqueness may be caused by one of two factors, either an institution deliberately trying to conceal information, or inadvertently, when poor informational design prevents users from successfully consuming the relevant search and retrieval functionalities (for instance, lack of open data indexing and/or a lack of accessibility due to poor UX design). As many blockchains are notoriously difficult to use for non-technical audiences, a blockchain may only ever partially help opaqueness, until there is more effort in the blockchain sphere that focuses on providing an adequate level of user experience and accessibility, particularly so for the digitally excluded populations. Therefore, blockchain limitations must be kept in mind whilst designing an appropriate solution.

When it comes to vulnerabilities and inefficiencies of traditional siloed institutions, there is no "one size fits all" blockchain solution to addressing those maladies. Nevertheless, appreciating that many vulnerabilities, such as customer data leaks, and inefficiencies, such as long turnaround times for processing requests in bureaucracies, are often caused by a mixture of causes, from the "single point of failure" factor to inadequate system design, can offer some hope that a better system can be designed, possibly with blockchains. Whilst small-scale complexities and vulnerabilities lend themselves to "quick fixes," outright institutional corruption calls for outright institutional reform, meaning that any decentralization approach would need to be complex and concerted, and not necessarily focused on blockchains, although they would certainly play a role for encouraging *trust* between the transacting parties. Multiple scenarios revolving around trust inspired the creation of blockchains in the first place (Gaggioli et al., 2019) such as enabling transactions in environments where people distrust each other, minimizing trust on central parties, and enhancing trust through transparency and computational verifiability. According to Golbeck's (2008) survey, online trust is required to "*foster successful interactions and to filter the abundance of information,*"

it also has three main targets – content, services and people. Therefore, when establishing the case for blockchain-mediated decentralization, one must be clear about the sort of trust that is required and the relevant reasoning. As depicted in **Figure 1**, by first establishing the reason for decentralization (the problem, the system and the case), can the right approach be sought, and the complexity of the efforts estimated.

Defining the Scope of Blockchain Decentralization

Defining the motivation for decentralization and clarifying the "business case" should naturally help the researcher who attempts to design a decentralized system using blockchains, equipping her with a better idea of what the scope of decentralization should be. When analyzing the reason for decentralizing, the researchers' attention will be ultimately brought to the ultimate human-centric constituents of socio-technical systems, i.e., the stakeholders, main actors and beneficiaries, all of whom will now be well-defined and documented, their relationships delineated, and incentives mapped out. Next, it will be necessary to define which elements of the system require decomposition and/or which workflows and processes may benefit from disintermediation. Decentralizing significant chunks of infrastructure may be achieved by the introduction of peer-to-peer infrastructures and distributed systems in place of server-based solutions but there needs to be a level of clarity as to which parts of the complete solution may have to remain centralized, and, as no blockchain is an island, which parts of this solution will need to be made interoperable, and to what extent. In terms of disintermediation, one has to plan for second system effects such as the scope in which previously non-existent intermediaries may be incentivized to form, and the negative "bloating" impact that this emergence would have on decentralization outcomes.

One has to keep in mind, however, that decentralization is as much technological as it is sociopolitical in nature. Thus, one will never just decentralize the infrastructure. What may need to be decentralized additionally are the modes of creation (for example through peer production), the rights and responsibilities of the stakeholder (such as fiscal responsibility), managerial control (through a decentralized autonomous organization), and governmental power (e.g., through devolution, citizen education and activation, or via co-management approaches). Regardless of the above, it could be the size of the organization that becomes an issue if the system becomes "too big to fail," which would lead to an antitrust sort of decentralization, so as to prevent predatory practices such as monopolies and/or oligopolies, and to encourage healthy competition that is fair and stimulating.

How Are We Decentralizing With Blockchains?

The final consideration of the decentralization action plan should be to establish the manner and mode of the proposed change in power/authority structure. Broadly speaking, decentralization can be implemented as either a top-down or a bottom-up exercise. As both approaches are vertical in nature, and decentralization emphasizes horizontal relationships, one must be mindful of the "exit strategy" for the temporary verticalization of efforts. Any top-down method will require an existing critical mass that may already be centralized, and to which it can be applied. In that approach, one has a choice of administrative reform, antitrust proceedings, deconstruction, deconcentration, decomposition, decoupling, co-management and power transfers. In contrast, bottom-up methods can be used to design decentralized systems from scratch and are more applicable to the sphere of blockchain. In those approaches, the available tools and approaches include mechanism design (which is about creating markets or other mechanisms matching individuals through the reverse application of game theory, i.e., through designing individual incentives and modeling the related pay-offs), distributed systems design (which is about creating the necessary infrastructure to relay and process the communications), encouraging active participation (which may involve education and campaigning activities), designing a decentralized autonomous organization (requiring software and Web skills to implement) or creating simple voting-oriented "democracy" dApps (distributed applications) by means of coding smart contracts and deploying them on blockchains. When designing these completely new mechanisms, infrastructures and applications from scratch, it is necessary to carry out enough experimentation and observation to rule out any negative externalities and second-system effects, such as new centralized loci of novel middle-men appearing in place of old ones that were removed.

On a technical level, smart contracts may only be viable if their intentions and actions are understandable to the wider population. This accountability can be achieved through coupling them with legal prose. This is achievable through establishing so-called Ricardian contracts (Grigg, 2004) which can link the legal intent to smart contracts in the form of tuples: *{legal prose, transaction parameters, smart contract code}* (see Clack et al., 2016). Additionally, the design of a decentralized system comprised of Ricardian-style smart contracts should involve the definition of stakeholders, their rights and responsibilities, economic incentives and preferences, and what top-down or bottom-up changes will be required. As there is currently no standardized format for this, a Linked Data ontology should be created to manage decentralized sociotechnical initiatives. An example of that can be found in Hoffman (2018) which proposes the use of smart contracts used in tandem with Linked Data documents to improve the transparency of global taxation.

Finally, all blockchain-mediated decentralization requires a flexible yet structured approach to governance design and implementation. The governance of a blockchain platform is not necessarily the same as that blockchain's rule-based operational logic. Instead, by blockchain governance we understand conflict resolution, dispute resolution, crisis management and all sort of sociotechnical mechanisms that facilitate higher-order decision-making regarding those cases that day-to-day operational logic does not address, including resolving uncertainties under incomplete contracts. Well-designed blockchain governance covers a plethora of aspects (Barrera, 2019) from proposal-making mechanisms to voting rights. It is also essential to keep in mind based on our **Table 1** findings that decentralized governance has different levels, and if a decentralized blockchain solution can successfully govern itself (higher-order governance)

then it can be successfully used to implement other types of governance such as fiscal or environmental governance (first-order governance). As a final note here, it is important to consider Arruñada and Garicano (2018) conclusions that in order to protect individuals and help coordinate their efforts, new forms of decentralized governance are required.

Blockchain-Mediated Decentralization

The authors build on Arruñada and Garicano (2018) definition of a "platform" as the "combination of software and hardware resources enabling the functioning of an exchange network," where "network" means "the community of individuals exchanging goods or services through a platform." With those definitions in mind, drawing from our systematic review findings, and taking into consideration the framework proposed in the previous chapter of this work as well as the distributed capitalism framework from Zuboff and Maxmin (2004) discussed earlier, we define "**blockchain-mediated decentralization of a system**" as (**Def. 1**): *the technique for designing a new federated support network using a combination of blockchain and P2P platforms, as a means for a particular community to address one or more shortcomings in terms of inefficiency, opaqueness or vulnerability of the existing system used by that community for a particular purpose, by introducing tamper-proof records, incentives, rules and workflows aimed at breaking up the inadequate concentrations of power in the existing system, in a way that allows any subsequent improvement to be reported with agreed-upon metrics.*

As an example, consider the creation of Bitcoin, whereby a novel network powered by a blockchain was designed, in the midst of the financial crisis and bank bailouts, for the global community to pay for products and services without relying on controversial central banks, utilizing the novel incentives of cryptocurrency mining, yielding an independent global payment system. Alternatively, consider MakerDAO running on top of Ethereum, where users can take out loans backed by crypto-backed collateral, in a way that is dynamically federated by multiple organizations, thus yielding a system that creates value by enabling independent access to credit, addressing the barriers to entry associated with traditional lenders, without the need for middle-man arbitrators. Also consider Steem (or its competing fork Hive, accessed through Peakd), a blockchain-based content rating dApp, where users vote on the content and stake their cryptocurrency, increasing the pay-out available to the creators of the most popular content, without biases associated with traditional media and publishing outlets. Using the above-introduced definition, it can be said that Bitcoin attempts the blockchain-mediated decentralization of currency, MakerDAO attempts the blockchain-mediated decentralization of credit, and Hive attempts the blockchain-mediated decentralization of web content curation and publishing. The success metrics for Bitcoin may include one of the AWDY metrics introduced earlier, such as the amount of money supply held by the top 100 accounts. Success metrics for MakerDAO and Hive may focus on the level of perceived improvement in accessibility and efficiency of the respective solutions, as compared to their centralized counterparts.

CONCLUSION

In this paper, the authors presented a historical outline, a systematic review, a framework and a definition for the unique meanings of blockchain-mediated decentralization. It was found that decentralization was mostly perceived in a positive and/or mildly neutral light and that the most important theoretical argument in favor of technologically-mediated decentralization was that it could facilitate desirable outcomes of socio-technical systems by improving their overall efficiency via mechanisms motivated by qualities such as transparency (openness, consistency), accountability and resilience (reliability, fault-tolerance, availability). Based on these findings, a novel answer was provided to the research questions set in the introductory section of the paper[12] – decentralized blockchain-mediated platforms can be understood as multi-stakeholder Web ecosystems acting as sophisticated support networks enabling peer-to-peer transfers of value and information, including goods and services, in a coordinated manner. The centralized loci of authority that these ecosystems are setting out to avoid range from central banks and big publishing houses to Big Tech infrastructure providers, and the type of power that is being dispersed in the process is usually related to breaking up functional silos and cutting out those middlemen that proved inadequate in existing systems that were deemed unfit for purpose, although more scientific rigor is required in capturing and measuring the dissatisfaction with the relevant centralized solutions (as well as the resulting perceived improvement yielded by decentralization), all of which needs to be further formalized.

Even though the bargaining power of the individual is believed to increase under decentralization, and there are other positive social effects reported in the literature, such as the increased perceived level of transparency potentially leading to greater accountability, new research is still needed to establish the evidence for the above. The major limitation here, however, is that the metrics used to measure the concentrations of power and authority are context-specific and require further domain-specific research to establish their definitions and the methodologies for calculating them. With that limitation in mind, the authors observed that in blockchain discourses, decentralization is often used as an ideal to strive for, but the weaknesses of currently nascent decentralization metrics lead to methodological complications that make objective reporting of decentralization unfeasible. Moreover, the binary positioning of "decentralization" and "centralization" is not an ideal approach as it obscures the motivations and rationales for the process. Instead, a sociotechnical system's complexity and allocation of authority are qualities positioned on a spectrum between purely decentralized and completely centralized, and it requires specific analyses geared toward specific communities. Toward this end, we noted how a blockchain set-up could simultaneously both have facets that are significantly centralized and others that are significantly decentralized, all of which require thorough

[12] "What is a decentralized platform exactly, and how is it different to a peer-to-peer one? And fundamentally, what sort of "authority" might such a decentralized platform be setting out to avoid, and what type of power is it dispersing?"

examination. Regardless of the methodological hurdles that were noted, based on their findings and analyses, the authors managed to propose a novel definition for "blockchain-mediated decentralization" as **Def. 1**[13].

Furthermore, this work outlined a framework for facilitating and clarifying technologically-mediated decentralization efforts. This framework emphasizes the human-centric constituents of socio-technical systems, i.e., the human stakeholders and the interactions between them, as well as the modes of content creation and managerial control. Governance was flagged up as a problem area, which requires an urgent concerted effort to better facilitate successful blockchain-mediated decentralization initiatives. Moreover, inadequate usability and user experience of blockchains may currently hamper the adoption of decentralized solutions by the communities beyond academia and "crypto" enthusiasts. Future academic work should, therefore, focus on refining the framework presented hereby, creating an ontology for managing decentralized sociotechnical initiatives, as well as improving the range of metrics available for measuring decentralization, and formalizing the existing ones. Additional research efforts may also be necessary to investigate to what extent "centralization" is the opposite of "decentralization" (which was an assumption made in some parts of this work), or whether the two processes are qualitatively different in ways that would disallow treating them as inverses of each other. Further definitions may also be needed to precisely specify blockchain-mediated decentralization across various contexts, such as finance decentralization, tax regime decentralization, content creation decentralization and governance decentralization.

[13]The technique for designing a new federated support network using a combination of blockchain and P2P platforms, as a means for a particular community to address one or more shortcomings in terms of inefficiency, opaqueness or vulnerability of the existing system used by that community for a particular purpose, by introducing tamper-proof records, incentives, rules and workflows aimed at breaking up the inadequate concentrations of power in the existing system, in a way that allows any subsequent improvement to be reported with agreed-upon metrics.

Ultimately, the dialectical thesis of this work posited that groups, communities and societies need to constantly coordinate complex match-making and decision-making processes, which are networked and increasingly online. Our work suggested that blockchains, with enough further work, can be useful for authority allocation in a human-centric manner that finds the source of value (economic and otherwise) in the individual operating within the technologically mediated "political compromise," with the caveat that scholarly rigor is required to stimulate constructive debate on this subject. A final suggestion for further work is that researchers scrupulously survey and investigate the relevant socio-psychological and political values and attitudes toward central authority and individual freedom that are prevalent in the relevant communities ("crypto" enthusiasts, post-cypherpunks, Bitcoin and blockchain core developers, social media blockchain evangelists, academic blockchain researchers, DeFi services providers) to elicit systematic insights into how those groups' core values inform their understanding of decentralization.

DATA AVAILABILITY STATEMENT

All datasets presented in this study are included in the article/supplementary material.

AUTHOR CONTRIBUTIONS

MH, L-DI, and ES contributed equally and agreed to be accountable for the content of the work. All authors contributed to the article and approved the submitted version.

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