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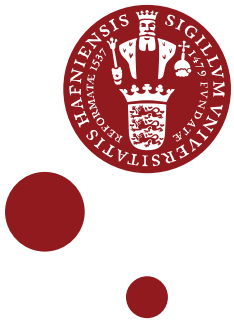

Ph.D. Thesis

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DAOs and Blockchain for Regulated Finance

Transformative decentralization

Supervisor: Associate Professor Omri Ross

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Abstract

The financial services industry is experiencing a significant shift with the rise of blockchain technology and decentralized finance (DeFi), which challenges the industry's high-cost centralized control approach. Distributed Ledger Technology (DLT), including permissionless blockchain and its novel organizational form, Decentralized Autonomous Organizations (DAOs), offer transformative potential through transparent, efficient, and decentralized financial transactions and governance structures. However, integrating these technologies into regulated financial services poses challenges due to the need to reconcile blockchain and DAOs' decentralized nature with stringent regulatory requirements.

This dissertation, developed over a three-year Ph.D. program, consolidates six publications into a comprehensive assessment framework for determining when DAOs and DeFi protocols are suitable for regulated financial services. It explores the effective implementation of DLT in regulated environments to reduce costs and enhance operational efficiencies. The research categorizes the publications by financial services domain, using prototyping and analysis to balance decentralization ideals with regulatory requirements.

The dissertation identifies key properties of blockchain and DAOs, such as transparency, immutability, and decentralization, assessing their applicability within traditional financial systems. It offers practical tools for evaluating the suitability and compliance of DAOs in regulated financial services, mapping DAOs to organizational design theory, and highlighting their potential to reduce transaction costs and enhance trust.

Using Design Science Research (DSR) methodologies, the dissertation develops robust frameworks, applications, and taxonomies through qualitative data collection, thematic analysis, and formal methods. It provides empirical insights and tools for practitioners, including frameworks for assessing DAO governance structures and regulatory compliance. The dissertation concludes that while DAOs and DeFi protocols show promise, their application in regulated financial markets remains challenging due to regulatory complexities arising from centralized control preferences and norms.

The dissertation contributes to Information Systems (IS) research by presenting an evolution of DAOs over time and proposing an evaluation framework to assess and enhance the understanding of blockchain technology and DAOs in regulated financial services. Further, the individual publications contribute to their respective field by presenting applicable building blocks for financial services and domain-specific use cases for the DAO ecosystem.

The research provides insights and tools that deepen the understanding of DAOs' potential and limitations in digital finance, offering a foundation for future research and practical applications. By incorporating law, economics, organizational theory, and IS perspectives, the dissertation highlights the need for new regulatory frameworks to accommodate DAOs and DLT. It suggests that while DAOs and DeFi protocols can reduce transaction costs and enhance transparency, their application in regulated finance is limited by compliance challenges and the need for complete decentralization.

The analysis suggests that 'sufficient decentralization' is a mirage and that complete decentralization on all three dimensions – technically, organizationally, and in service availability to the public – is the only viable option for DeFi in regulated financial markets, using the EU's recent regulation for digital finance. While we have yet to see whether the new EU regulation and this high bar for decentralization will mean the end for DeFi and financial services DAOs in the EU, blockchain technology appears generally beneficial for finance involving untrusted parties, where intermediaries usually fulfill this role at a very high socioeconomic cost.

Resume

Finanssektoren står overfor betydelige ændringer med fremkomsten af blockchain-teknologi og decentraliseret finans (DeFi), som udfordrer industriens omkostningsniveau og centraliserede tilgang til kontrol. Distributed Ledger Technology (DLT), herunder åbne blockchains tilbyder gennemsigtige, effektive og decentraliserede finansielle transaktioner og styring igennem dets foretrukne organisatoriske form, Decentralized Autonomous Organizations (DAOs),. Integrationen af disse teknologier i regulerede finansielle tjenester er dog udfordret af behovet for at forene blockchain og DAOs' decentraliserede natur med strenge regulatoriske krav.

Denne afhandling dækker et treårigt ph.d. forløb og konsoliderer seks publikationer i en analyseramme til vurdering af, hvornår DAOs og DeFi-protokoller er egnede til regulerede finansielle tjenester. Afhandlingen udforsker implementering af DLT i regulerede miljøer med henblik på at reducere omkostninger og forbedre effektivitet. Forskningen inddeler fokuserer de seks publikationer i forskellige finansielle ydelsesområder ved hjælp af prototyper og analyser, der søger at balancere idealer om decentralisering med regulatoriske krav.

Afhandlingen identificerer egenskaber ved blockchain og DAOs, såsom gennemsigtighed, uforanderlighed og decentralisering, og vurderer deres relevans i traditionelle finansielle systemer. Den leverer praktiske værktøjer til at evaluere egnetheden af DAOs indenfor reguleret finans tjenester, kortlægning af DAOs i forhold til organisationatorisk design teori og teknologiernes potentiale til at reducere transaktionsomkostninger og øge tillid.

Igennem Design Science (DSR) metoder demonstrerer afhandlingen rammeværk, applikationer og taksonomier via kvalitativ dataindsamling, tematisk analyse og formelle metoder. Den giver empiriske indsigter og værktøjer til praktikere, herunder rammer til vurdering af DAO implementering og DeFi protokoller i forhold til compliance krav og forventninger. Afhandlingen konkluderer, at selvom DAOs og DeFi-protokoller viser potentiale, forbliver deres anvendelse i regulerede finansielle markeder udfordret af regulatorisk kompleksitet, hidrørende i traditionelle centralistiske kontrolpræferencer og normer.

Afhandlingen bidrager til Information Systems (IS) forskning med en analyse af DAOs' tidsmæssige evolution samt en ramme for vurdering af blockchain-teknologi og DAOs i reguleret finans. Desuden bidrager de enkelte publikationer til deres respektive felter ved at præsentere domænespecifikke anvendelser for DAO-økosystemet, igen med fokus på finansiel service.

Afhandlingen giver indsigter og værktøjer, som uddyber forståelsen af DAOs' potentiale og begrænsninger i digital finans og foreslår en agenda for fremtidig forskning og praktiske anvendelser. Ved at indrage perspektiver fra jura, økonomi, organisations teori og IS, fremhæver afhandlingen behovet for nye regulatoriske rammer for DAOs og DLT. Den vurderer, at selvom DAOs og DeFi-protokoller kan reducere transaktionsomkostninger og øge gennemsigtighed, er deres anvendelse i reguleret finans begrænset af compliance og især kravene til decentralisering.

Analysen antyder, at 'tilstrækkelig decentralisering' er en illusion, og at fuldstændig decentralisering på tre dimensioner – teknisk, organisatorisk og i måden hvorved en finansiel tjeneste gøres tilgængelig for offentligheden – formentlig er den eneste mulighed for DeFi, som reguleringen pt. er implementeret i regulerede markeder, med udgangspunkt i EU's nye lovgivning for digital finans. Selvom vi endnu ikke har set, om den nye EU regulering og den høje standard for decentralisering vil betyde afslutningen for DeFi i EU, synes blockchain-teknologi generelt at være gavnlig i transaktionsmiæjøer, hvor parter ikke har tillid til hinanden, fremfor mellemmænd med høje socioøkonomiske omkostninger.

Preface

Distributed Ledger Technology (DLT), including blockchain, has emerged as a cornerstone innovation in digital transformation, influencing electronic marketplaces, socio-cultural landscapes, financial markets, and regulatory frameworks. This thesis consolidates six individual contributions developed during my Ph.D. program at the University of Copenhagen's Department of Computer Science from August 2021 to July 2024. My research coincided with major market developments, including the rise and fall of Decentralized Finance (DeFi) and the crypto market since 2020, the EU's digital finance regulations for digital assets, and the renewed rise of DeFi due to institutional crypto adoption. These events provided intriguing research opportunities.

Regulation is a significant challenge in this sector, as global regulatory bodies take different approaches to the inherently decentralized technology. My research focuses on the intersection of technology and regulation, specifically addressing when and how to regulate permissionless blockchain applications in financial services. Driven by my passion for understanding blockchain's disruptive potential in traditional finance, my research aims to understand and find methods and tools to evaluate the suitability and conditions under which DLT, blockchain, and the novel organizational form Decentralized Autonomous Organizations (DAOs) are suitable for regulated financial services.

This thesis has two parts. Section 1 is an essay that consolidates the findings from the six individual publications; it is organized into nine chapters. Chapter 1 serves as an introduction to the topic and presents the research question. Chapter 2 outlines the theoretical framing, and Chapter 3 the methodological aspects. Chapter 4 provides a background with the foundations of blockchain technology, compliance, DeFi, DAOs in an organizational context, and DLT in traditional finance, summarizing the technical properties of blockchain technology, DeFi, and DAO characteristics. Chapter 5 offers a deeper dive into DAOs and the properties of blockchain technology in the context of DAOs. Chapter 6 derives the evaluation items for the framework from the individual publications with an evaluation of the framework on three prominent DeFi protocols. Chapter 7 provides a critical discussion from a regulatory, technical, and practical perspective. Chapter 8 concludes, and Chapter 9 suggests further research avenues.

Section 2 of this thesis compiles the six publications, including five peer-reviewed papers and one currently under review. This article-based thesis presents the papers in their published format. The following publications, sorted by peer-reviewed publication date, are included in this thesis: In addition, the dissertation includes one unpublished paper, paper 6, currently under review. The six papers are:

1. When is a DAO Decentralized?
   Axelsen, H., Jensen, J. R. and Ross, O. (2022), Complex Systems Informatics and Modeling Quarterly, (31), pp. 51–75. doi: 10.7250/csimq.2022-31.04.
2. How should DAOs be regulated?
   Axelsen, H. and Ross, O. (2022), Amplify, 35(10), pp. 8–18.
3. Trading Green Bonds Using Distributed Ledger Technology
   Axelsen, H., Rasmussen, U., Jensen, J. R., Ross, O., and Henglein, F. (2023), European Conference on Information Systems. ECIS 2023. Research Papers. 340.
4. DLT for compliance reporting
   Axelsen, H., Jensen, J. R. and Ross, O. (2023). Complex Systems Informatics and Modeling Quarterly (CSIMQ), (35), pp. 92–103. doi: https://doi.org/10.7250/csimq.2023-35.04.
5. Do You Need a DAO?

Axelsen, H., Jensen, J. R., and Ross, O. (2024), European Conference on Information Systems. ECIS 2024. Research Papers. 1643.

6. Scaling Culture in Blockchain-based Gaming
   Axelsen, H., Axelsen, S., Licht, V., and Potts, J., pre-print https://arxiv.org/abs/2312.07693

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Lastly, I am deeply thankful to my wife, Charlotte, for your constant love, patience, shared excitement, and unwavering support of my curiosity and career shift from consulting and professional services to academia and on to new ventures.

This journey has shaped me as an academic and equipped me with new skills and insights to prepare for my next venture.

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Glossary

Abbreviations with multiple meanings in common language are defined in this section. These definitions are assumed throughout this dissertation.

ART	Asset Reference Token
CASP	Crypto Asset Service Provider
DAO	Decentralized Autonomous Organization
DeFi	Decentralized finance, a blockchain-powered peer-to-peer financial system
DLTR	DLT pilot regime regulation
EMT	E-money token
€	Euro
MiCA	Markets in Crypto Asset Regulation
MiFID	Markets in financial instrument directive
NFT	Non-fungible token
USD	US dollar

1. Introduction

Over the years, financial crises have driven the creation of new and additional regulations, enhanced governance, and improvements in utility infrastructure to manage processing and mitigate systemic risks within financial systems. This has resulted in a complex web of interactions today, where financial systems are marked by multiple versions of the truth and isolated layers of data and regulatory interpretations, leading to fragmented markets. Consequently, there is minimal transparency and high maintenance costs at the institutional level, making the existing infrastructure vulnerable to technological threats and unnecessarily complicated. This complexity arises because trading activities and systems for payments, clearing, settlement, collateral, capital, and asset management were developed as tactical responses at different times for different needs. Additionally, there has been a lack of emphasis on proper data and messaging standards by market participants and regulators, with no focus on system integration. The overall result is a compartmentalized infrastructure that is not equipped for continuous 24/7/365 processing or reporting [3][4].

Blockchain and Distributed Ledger Technology (DLT) have significant potential for reducing dependencies among service providers across various financial sector activities. These activities include cross-border payments, trade finance, and post-trade operations such as clearing, settlement, and market making. Early research has demonstrated the utility of these technologies in cross-sector back-office functions, with a strong consensus that DLT could revolutionize the securities and settlement industry [5]. By standardizing and streamlining processes, DLT can save costs by reducing unnecessary duplication of activities and improving reconciliation, reporting, and risk management. While there is an ongoing debate among industry players about whether modernizing current post-trade practices and laws to enable real-time settlement necessarily requires DLT or blockchain technologies, DLT offers numerous opportunities for optimizing various aspects of the post-trade cycle. These include master data management, asset/securities issuance and servicing, confirmed asset trades, trade/contract validation, recording and matching of complex asset types, netting and clearing, reconciliation, collateral management, settlement, and risk management [6][7][8][9].

Decentralized Finance (DeFi) is a peer-to-peer and peer-to-contract financial system that utilizes DLT-based smart contracts to ensure integrity and security. It encompasses stablecoins for payments and exchanges, tokens representing digital replicas of traditional assets, trading platforms with automated market making, derivatives exchanges, insurance instruments, and lending products. DeFi's open-source, transparent, permissionless, and largely unregulated nature fosters hyper-competition and rapid innovation, enabling it to penetrate traditional financial services quickly. Its borderless and pseudonymous characteristics allow it to reach anyone with internet access or a smartphone, making it more efficient, transparent, and accessible than traditional finance. DeFi's composability also enables the quick creation of new services by combining multiple applications and protocols, outpacing the innovation rate of traditional finance, which is heavily regulated and operates in an exclusive market with high entry barriers. However, DeFi is still an emerging technology with unique risks and vulnerabilities, including frequent exploits and scams due to minimal regulation and oversight.

In consideration of the popularity and perceived benefits of DeFi in the late 2010s, regulators gained focus on the technology, with the EU leading the way with their 2020 Digital Finance package that included novel regulations such as the Markets in Crypto Asset Regulation (MICA) and the DLT pilot regime regulation (DLTR), coming into effect in 2023-2025.

Before starting this Ph.D., I was a consultant specializing in risk and compliance matters. Originally trained as a lawyer, I focused on large banks for many years, most recently on the Single Supervisory Mechanism and the supervision of the largest banks within the EU’s Banking Union.

Given this background and the evolving regulatory agenda, the overall theme for this Ph.D. research project is to investigate how to bridge the gap between traditional financial industries and emerging DeFi tools by exploring how these novel technologies could reduce costs and mitigate risks in key financial processes, with a focus on compliance challenges associated with blockchain technology.

The central thesis of this integrative chapter of the dissertation is that decentralization in the context of regulated financial services is three-dimensional: (i) The organization must be decentralized, (ii) the technology must be decentralized, and (iii) the provision or enablement of the service offering must be decentralized.

Blockchain and DLT exemplify the potential for decentralization within information systems. These technologies offer secure, transparent, immutable transaction and record-keeping mechanisms without central oversight. When considering the financial services perspective, decentralization requires an additional element that goes beyond the organizational and technical decentralization features of the way computer science scholars describe DLT/blockchain characteristics [10].

Along with tamper-proof event recording and guaranteed resource preservation (no double spending), this three-tiered decentralization requirement informs the unique environment for a novel blockchain-based organization form, the Decentralized Autonomous Organization (DAO), in regulated finance. We call this '*transformative decentralization*,' the strategic process of distributing control, power, or decision-making from centralized agents to a dispersed and varied group of stakeholders across technological and social domains, where decentralization, as regards regulated financial activity, as a mechanism involves three layers, each with significant implications for the field of DeFi, the primary application of DAOs.

Binding the work together is the potential of decentralized and distributed technology to reimagine traditional models. This invites the reader to consider the functionalities these technologies offer and the broader implications of their adoption, given the regulatory developments related to digital assets. Later, investigating how the technology can propose systemic shifts in green finance, critiquing the operational reality of DAOs, and navigating the evolving regulatory landscapes, this work has uncovered elements for understanding the complexities inherent in decentralized systems.

Blockchain and other DLT have increasingly found product-market fit in use cases across industries, including logistics and finance. More recently, their integration with AI and other technological advancements is accelerating a shift toward blockchain-based business models [11]–[14] in many sectors.

With the approval by the US regulators of several new exchange-traded funds for crypto assets and EU's MICA in parallel coming into effect in 2024, tokenization, i.e., the process of creating unique digital representations of assets, referred to as tokens [2], on DLT/blockchain networks, as used in DeFi, have also gained traction in traditional finance after years of promise and experimentation. The benefits, including programmability, composability, 24/7 availability, instant global collateral mobility, equitable access, and enhanced transparency, enable traditional financial institutions to achieve operational efficiencies, increase liquidity, and explore new revenue opportunities.

Another unique benefit is the incentive aspect of public blockchains, which encourages rapid adoption, unlike digital platforms outside the blockchain ecosystem.

Network effects rely on reaching a critical mass, where the product or service becomes more useful as more people use it. Without critical mass, the appeal of joining the network is limited. However, blockchains differ because they provide financial benefits even when their application utility is still developing. Figure 1.1 below illustrates the difference. This 'Web3' approach introduces the concept that every product is also an investment opportunity. In traditional 'Web2' social networks, users adopt new platforms if they find them appealing and their friends are on them. These factors reinforce each other, as better-designed networks attract more users. Web2 networks are usually funded by venture capitalists (VCs), who invest based on the network's features and potential user base. Both users and investors focus on the product's intrinsic quality and appeal. However, in Web3 social networks, users also consider potential financial gain, quality, and network utility. Users are more likely to join networks that offer monetary rewards, driven more by profit potential than the platform's features [15].

Without diving into behavioral science and cognitive bias, it seems that the chance to make money often outweighs other considerations for humans. Hence, regulators are concerned about how tokens are offered or made available to the public.

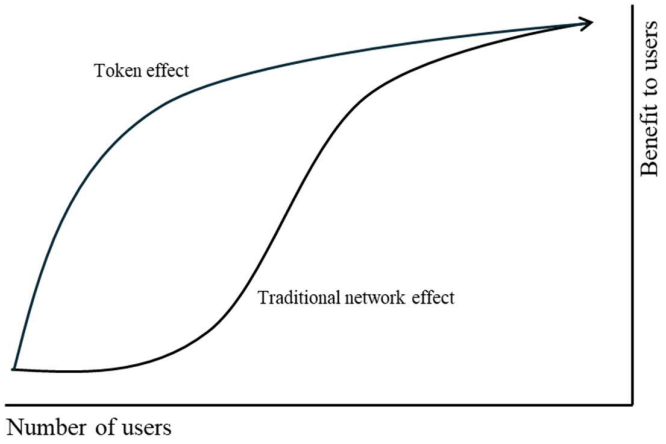

Figure 1.1. Token effect vs network effect, based on [16].

Reflecting on the strategic significance of this technology, Larry Fink, CEO of BlackRock, a very large investment manager, has recently suggested the next step is that tokenization should cover all financial assets, envisioning a unified ledger for every stock and bond. Also, the Bank for International Settlement (BIS), an international financial institution owned by member central banks, reflects that the future financial system, the 'Finternet,' will leverage technologies for tokenization [17]. I will come back to this development later, but as motivation for this dissertation, the trend is clear – as more institutions adopt and scale tokenized products, including bonds, funds, private equity, and cash, the digitization of assets appears increasingly inevitable, with the technology maturing and demonstrating clear economic benefits [18]. Yet, the question remains if this future will be decentralized and permissionless or under centralized control.

In this evolving landscape, the DAO is a novel form of blockchain-based organization. DAOs propose fundamentally new approaches to governance through token economics and smart contracts, challenging traditional financial and regulatory infrastructures [19]–[21]. DAOs' primary application, DeFi, accounts for more than 40 pct of DAOs [22]. While the general crypto market and DeFi exploded in growth during my studies [23], they subsequently suffered significant backlash due to governance failures of prominent actors such as FTX, Terra Luna, and Celsius [24]. Meanwhile, DAOs continued to proliferate [25], which increasingly informed the research direction towards DAOs as a phenomenon.

The rise of DAOs marks an important shift in organizational frameworks with transformational effects, particularly in terms of user community dynamics, ownership, and value exchange [26]. This shift has been explored in studies highlighting DAOs' potential to meet the changing operational and business needs of organizations, offering transparency and efficiency through smart contracts [27] and value add performance [28] with global reach. Scholars have developed specific decision-making processes and tools tailored for DAO platform environments [29]–[31], and comparative analyses of various DAO platforms shed light on the nuances and operational differences among these platforms [32], their content [33] and underlying blockchains [34]. Empirical research has also shown that the critical decentralization objective often fails in DAOs [33][34], indicating that while DAOs promise a novel organizational structure, their practical implementations may not fully align with theoretical aspirations. In some cases, what seems to be a decentralized autonomous organization might actually be a distributed automated operation under centralized control.

This divergence from traditional organizational frameworks, where regulation and centralized governance dominate, spotlights the inherent challenges DAOs face – balancing decentralized autonomy, effective governance, and compliance with regulatory expectations [35][36]. The romanticism of decentralization – sometimes spurred by extraordinary financial gains during bull markets – must be tempered with recognizing that decentralization does not inherently entail risk-free or more effective. Prominent DeFi platforms like Compound [39], Maker [40], and Uniswap [41]

illustrate how DAO structures distribute both returns and risks, redefining notions of equity and consumer protection [40][41]. This complex interplay of innovation and risk calls for a tailored organizational design framework for DAOs to address their unique strengths and weaknesses.

This cumulative Ph.D. dissertation investigates blockchain tooling from a decentralized and traditional finance perspective. It demonstrates that distributed ledger technology (DLT) may play an important role in modernizing traditional finance and capital markets due to its regulatory compatibility and operational benefits. However, permissionless DLT faces significant challenges in this context. The research shows that Decentralized Autonomous Organizations (DAOs), whose primary application is Decentralized Finance (DeFi), provide minimal to no utility in the critical financial infrastructure of mature markets. Further, DAOs have limited utility within other mature financial systems and only if they achieve genuine decentralization. Even then, DAOs must continuously comply with regulatory requirements and stakeholder expectations.

Qualifying DAOs as organizations is challenging. Scholars have begun this qualification by proposing frameworks that not only assess the suitability of DAOs compared to traditional models but also explore the broader implications of decentralized governance [35][36][42]–[44]. These frameworks seek to integrate the foundational elements of organizational design with the unique characteristics and principles of DAOs, marking an important step in the evolution of organizational theory in the age of blockchain and decentralized technologies. Scholars increasingly call for the expansion of DAO research, highlighting a multitude of research areas across its theoretical groundings in Transaction cost theory, Theory of institutions for collective action, Agency theory, and Socio-materiality theory, as captured in [45]'s integrative model and research agenda.

This integrative chapter synthesizes generalizable conclusions from the results of the six research papers in the dissertation. In addition, as the culmination of my Ph.D. studies, the chapter presents additional research specifically focusing on DAOs as organizations in financial services, asking the following separate research question:

'*Are DAOs and DeFi fit for regulated financial activity?*'

Considering DAOs have emerged only in the past decade, this is a very big question to investigate, and we cannot draw firm conclusions, as the concept is still evolving. In charting the path from the technical underpinnings of DAOs and blockchain vs. other DLT to the strategic considerations underpinning organizational decisions and regulatory response, the research seeks to illustrate the complexities of DLT and blockchain-based DAOs as modern organizational forms, analyzing different use cases and markets. The result is perhaps more of a taxonomy and framework to inform users of DAOs and DeFi.

As we demonstrate in this chapter, within highly regulated mature markets with centralized control preferences and low-risk appetite, the permissionless public concepts struggle, whereas, in less mature markets, they might excel. We are only at the start of this DLT/DAO journey. This integrative chapter contributes to the Information Systems (IS) discourse on DAOs and organizational theory and practice by proposing two key dimensions where DAOs are unique, further integrating decentralized governance models into established organizational frameworks. It also contributes to the multidisciplinary DeFi and DAO discourse and practitioner agenda with an assessment tool to analyze DAO suitability in regulated finance. By focusing on the key dimensions that inform the effective use of DAOs, the combined research contributes to a deeper understanding of how DAOs and DLT affect organizational practice within the evolving landscape of digital finance.

Each of the individual research papers forming part of this dissertation contributes the following results:

1. When is a DAO Decentralized? (Paper 1 [47]) asks the research question, *'When is a DAO (sufficiently) decentralized?'* This research question is important for all DAOs and decentralized protocols aiming to provide financial services. The research advances the understanding of decentralization in the context of DAOs in financial services regulation, such as MICA, by conducting a thematic analysis that integrates existing literature with insights from expert interviews. It posits that DAOs need to achieve a certain level of

decentralization to avoid regulatory compliance mandates. The research defines "sufficient decentralization" and uses Design Science Research (DSR) to offer a comprehensive framework artifact for evaluating decentralization with five aggregate dimensions specific to DAOs.

2. How should DAOs be regulated? (Paper 2 [48]) is more of an opinion or commentary. The paper discusses the recent regulatory sanctioning of a DAO and a set of autonomous smart contracts, the infamous case of Tornado Cash, a smart contract used by international crime syndicates to launder money. It discusses how this enforcement approach by US regulators impacts the future of DAOs, contributing a perspective on regulatory enforcement actions and how (not) to regulate DAOs. The research highlights the importance of the user interface when anyone offers otherwise regulated financial services in a decentralized context.
3. Trading Green Bonds Using Distributed Ledger Technology (Paper 3 [49]) asks, *'To what extent can distributed ledger technology (DLT) facilitate the issuance, trading, and settlement of regulated financial instruments (green bonds) to finance carbon capture based on verified carbon credits in voluntary carbon markets?'* The paper examines the application of DLT in critical financial infrastructure for securities trading and settlement, as governed by the EU's DLT pilot regime (DLTR), from the perspective of traditional finance. As far as we know, this is the first regulatory sandbox with an EU national competent authority testing DLT for securities issuance, trading, settlement, and custody, applying the novel regulation. The research is important for established financial institutions and new entrants seeking to disrupt critical financial infrastructure with DLT. It uses DSR to create a near-production-level technology artifact, TRL7 [50]. A key finding of the research is that regulatory requirements for finality, throughput, and settlement of the payment leg in securities trading under EU regulation render public permissionless blockchains, and consequently decentralized finance, less appropriate for capital market operations. Instead, the study suggests a multi-sharded architecture, where nodes uphold coordinated responsibilities within a permissioned private network using deterministic consensus mechanisms, which is more suitable and aligns more effectively with the demands of critical financial infrastructure.
4. DLT for compliance reporting (Paper 4) [51]) adopts the perspective of traditional finance and uses DSR to illustrate how DLT can disrupt compliance reporting in traditional financial services. It asks, '*To what extent could the adoption of DLT-based solutions optimize ITS compliance reporting for banks and organizations in the EEA?'* ITS risk reporting involves over 500 intricate requirements and includes thousands of tables with thousands of data fields. More than 5.000 banks in the EEA must comply with this reporting requirement with an estimated annual spend of more than €12Bn per year. This is a very expensive regulation, amounting to one-third of banks' compliance costs. The research is important for incumbent financial institutions and supervisors as it highlights how DLT can enable a high degree of automation in compliance reporting through a 'pull model,' allowing regulators to access compliance data in near real-time. This approach facilitates the aggregation of macroeconomic risk exposures, enhances supervisory oversight, and reduces costs compared to the traditional method, which relies on multiple lines of defense to ensure quality. The paper's main contribution is demonstrating the affordances and benefits of DLT in compliance reporting.
5. Do You Need a DAO? (Paper 5 [38]) asks, '*Is a DAO suitable for your organizational needs?'* The paper contributes a gated decision-making framework designed through a thematic review of academic and grey literature on DAOs. The framework, demonstrated through five scenarios, underscores the gaps between DAOs' theoretical potential and their practical challenges in regulated finance. The research-in-progress is important for aspiring and existing DAO communities who do not know how to organize communities around blockchain-based business models. The findings underpin the completed research presented in this integrative chapter.
6. Scaling Culture in Blockchain-based Gaming (Paper 6: [52]) does not deal directly with DAOs or DeFi. Still, it analyses the use of Large Language Models (LLMs) in the form of generative pre-trained transformer (GPT) models, now commonly known as generative artificial intelligence (AI). The paper asks *'Are LLMs an option for identifying, nurturing, and*

sustaining culture in gaming communities going through hypergrowth?'. It focuses on managing off-chain governance in pseudonymous blockchain-based gaming communities. The mixed-method research incorporates thematic analysis and analytics to understand cultural production and group formation. It introduces an analytical framework utilizing GPT models to enhance the understanding and management of decentralized communities from the 'off-chain' governance perspective. The findings are replicable to DAOs as well as to traditional firms and are important, as they offer deeper insights into community dynamics and how off-chain and on-chain incentives can be aligned as an internal control mechanism, helping community moderators identify pseudonymous actor intent, manage toxic behavior, reward positive actions, and gauge community sentiment. From a regulatory perspective, the research demonstrates how generative AI can automate internal controls, ensuring compliance and maintaining order and proper culture within communities across decentralized and traditional finance while potentially reducing agency costs by 95%. From a transaction cost theoretical perspective, this reduced agency cost is essential for DAOs to be relevant as alternative forms of organization. Without going into full details of the impact of AI, the recent advancements in AI are being embraced by everyone, including incumbents and DAOs in finance. The EU and OECD definition of AI as "a machine-based system that is designed to operate with varying levels of autonomy and that may exhibit adaptiveness after deployment" [53] adds a perspective of 'adaptiveness' to the 'A' in DAOs, if AI-enabled.

This integrative chapter extracts and synthesizes generalizable conclusions from the above papers while also finalizing the research started in paper 5 [38]. It offers a critical viewpoint that is pertinent to the field by (i) examining the need for new regulatory approaches that accommodate the unique characteristics of DAOs and DLT, (ii) analyzing how DAOs challenge traditional organizational forms and regulations and the implications for governance, compliance, and decentralization; (iii) exploring the technical and socio-technical dimensions of DLT in various applications; (iv) considering how these technologies influence organizational culture and support operational strategies; and (v) evaluating the suitability of DAOs for different organizational needs, with a particular focus on regulated financial activity. Figure 1.2 illustrates how each paper contributes to the framework we present later in this integrative chapter.

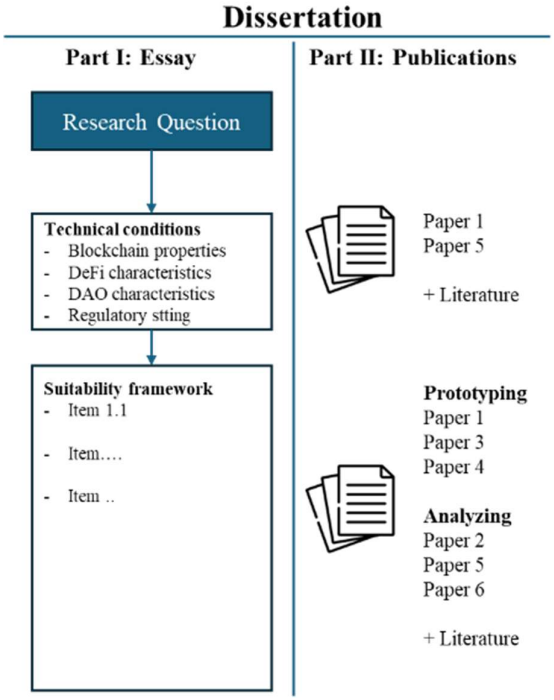

Figure 1.2. Overview of the method for the integrative chapter of the dissertation.

The synthesis of research findings in this integrative chapter is as follows: Chapter 2 provides a theoretical framing. Chapter 3 includes higher-level reflections on methodologies across sub-studies in the research papers and integrative chapter. Chapter 4 provides background on DLT, blockchain, DeFi, and DAOs. Chapter 5 takes a deeper dive into DAO fundamentals. In Chapter 6, we design an expanded framework to assess DAO and DeFi protocol suitability, focusing on regulated financial activity and evaluating the framework of three prominent DeFi protocols. Chapter 7 discusses findings and observations across all papers and the integrative chapter. Chapter8 contains the conclusion; Chapter 9 contains the limitations and a future work agenda.

2. Theoretical framing

The collection of papers presented in this dissertation showcases an effort to enhance my theoretical contributions throughout my Ph.D. journey. Scholars agree that DAOs have multidisciplinary theoretical groundings [45], mainly in social sciences:

(i) Transaction cost economics posits that organizations exist to minimize the transaction costs associated with economic exchanges [54]. By leveraging blockchain technology, DAOs aim to reduce these costs through transparent, automated governance and smart contracts [53][54].

(ii) Institutional theory for collective action [57] posits that DAOs function according to principles of collective action, where virtual participants collaboratively create decision-making frameworks to design, discuss, and vote on rules that govern software protocols and manage the exchange of shared resources. Some scholars even argue that DAOs should be governed as a 'Commons' [56][57].

(iii) Agency theory [60] suggests that DAOs offer a novel approach to principal-agent relationships by automating the agent through a decentralized network of computers. This reduces the agent's self-interest issues that contribute to the agency problem of moral hazard.

(iv) Sociomateriality theory [61] originates in sociotechnical theory and posits that the social and material aspects of DAOs become intertwined, creating new organizational designs that empower peer-to-peer communities to function without human intervention. The sociomateriality of DAOs encompasses socio-material practices and interactions, human-machine agency, and institutional change.

(v) Institutional theory [62] emphasizes that organizations strive for legitimacy by conforming to societal norms and regulatory expectations. Institutional theory is broad, encompassing all forms of institutions. In contrast, the institutional theory of collective action is focused on managing common-pool resources and collective governance. DAOs' theoretical foundation is demonstrated by their pursuit of legitimacy, which often involves adopting behaviors and practices like those of traditional organizations despite their inherently decentralized nature.

But there is an additional grounding in natural sciences with a focus on positivism. Seeking to explain phenomena through empirical evidence, experiments, and observation, aiming to prove hypotheses through quantitative data, reproducibility, and rigorous testing; the discourse typically revolves around confirming theories or discovering new facts through experimental validation [63]. This involves principles from systems theory, cybernetics, evolutionary biology, network theory, game theory, and more, as discussed in paper 1 [47], where we suggest DAOs can be viewed as complex adaptive systems where decentralized decision-making and automated processes enable self-regulation, similar to cybernetic systems with feedback loops and information flow. Like in paper 6 [64] and in line with cultural science [52] DAOs evolve through adaptation and selection, similar to evolutionary biology, while network theory explains their decentralized, robust structures.

In contrast, social sciences often adopt an interpretive approach, which describes societal structures and critically interprets how these structures emerge and affect individual autonomy and social change. This approach is usually context-dependent and not easily measurable; the discourse

frequently involves critiquing existing theories and frameworks to develop a deeper understanding ('Verstehen') and offer new perspectives [65].

The research presented in this dissertation addresses contemporary challenges by investigating and designing innovative technological solutions with an information systems (IS) lens, with multifaceted applications of blockchain/DLT, and to enable a transformative shift towards decentralized and distributed systems, and especially DAOs as a phenomenon.

As such, the theoretical grounding of this dissertation is more aligned with social sciences than natural sciences.

From the perspective of transaction cost economics, paper 1 [47] offers insights into decentralized organizations, highlighting how DAOs reduce transaction costs through transparent, automated governance and smart contracts. In addition, this integrative chapter emphasizes that DAOs, despite potential cost reductions, must achieve genuine decentralization and regulatory compliance to provide utility in mature financial systems. Later, in presenting the suitability assessment framework, we also demonstrate how a DAO's objective function influences its transaction costs.

From the perspective of institutional theory for collective actions, paper 2 [48] discusses the transformational shift in regulatory paradigms posed by DAOs and provides future directions for their development. Paper 5 [38] contributes a 5-step gated decision-making framework derived from thematic analysis, theoretical insights into DAO capabilities and organizational structures, and a defense of DAOs' pursuit of legitimacy through adopting behaviors and practices like traditional organizations, aligning with societal norms and regulatory expectations.

From the perspective of agency theory, paper 4 [66] designs and evaluates a conceptual artefact for compliance, reducing agency problems by automating the agent through decentralized networks. Paper 6 [52] contributes perspectives on generative AI and agency cost in cultural production and internal control. The central thesis of the integrative chapter emphasizes the multidimensional nature of decentralization in the context of regulated financial services, which includes decentralizing the organization, technology, and service provision. In later sections of this chapter, we comprehensively explore how decentralization impacts various organizational aspects, including principal-agent dynamics. We also examine how regulatory requirements and stakeholder expectations must be met, even with genuine decentralization. Hence, this integrative chapter highlights the novel approach DAOs offer to principal-agent relationships, addressing moral hazard issues through decentralized automation, reducing conflicts of interest, and ensuring accountability through decentralized mechanisms.

From the sociomaterial/sociotechnical theoretical perspective paper 1 [47] uses the Design Science Research (DSR) method [67][68][69] and thematic analysis [70] to provide practical insights into decentralized organizations, demonstrating how sociotechnical constructs in DAOs reduce transaction costs through transparent, automated governance and smart contracts. Paper 3 [49] also uses DSR to contribute a novel artifact that addresses the need to scale voluntary carbon markets, highlighting the interplay between social and material aspects in capital market infrastructures. Paper 4 [66] utilizes DSR methodology to design and evaluate a compliance-related artifact, showcasing the integration of sociotechnical elements to meet regulatory and operational needs. Paper 5 [38] develops a 5-step gated decision-making framework derived from thematic analysis, contributing to the theoretical understanding of DAO capabilities and the socio-material practices involved in their governance. Paper 6 [52] explores the intertwining of social and material aspects in semi-decentralized, pseudonymous gaming communities, focusing on transmedia storytelling, governance of blockchain-based business models, and sustainability. Finally, this integrative chapter discusses how the sociomateriality of DAOs fosters new organizational designs empowering peer-to-peer communities, reflecting on the socio-material practices, human-machine agency, and institutional changes brought by DAOs.

From the institutional theoretical perspective, paper 3 [49] investigates the practical implications and limitations of DLT in scaling voluntary carbon markets, emphasizing the need for market integrity and stability. This integrative chapter differentiates between the broad scope of institutional theory

and the specific focus on collective action, stressing DAOs' efforts to conform to regulatory expectations and gain legitimacy.

3. Methodological aspects

Given the multidisciplinary groundings, this dissertation's methodological approach is multidisciplinary, incorporating perspectives mainly from law, economics, organizational theory, and practice. All six papers have a regulatory and IS perspective.

The six papers are arranged by their final publication dates rather than the chronological order in which they were developed during my PhD program. While focusing on a specific domain, each paper contributes to a holistic understanding of how decentralized technologies can reimagine traditional structures, offering greater transparency, enhanced accountability, and improved operational efficiencies.

Scholars and practitioners discuss the 'D,' A, ' and 'O' in DAOs, which concern decentralization, autonomy, and organization as well as distribution, automation, and operations. We will touch further on these meta-characteristics later from a taxonomy perspective, as there is a difference between a Decentralized Autonomous Organization and a Distributed Automated Operation.

The work across the six papers consists of mixed methods research that combines qualitative and quantitative research techniques, methods, data, and concepts to gain a better understanding of research problems [71]. The different approaches address research questions from multiple perspectives and have been useful in exploring complex phenomena where neither qualitative nor quantitative methods alone suffice. The mixed methods approach has proven to be effective in research areas involving complex interaction in IS phenomena, as it gathers empirical evidence from various sources and types of data through triangulation [72]–[74].

Across the six papers, table 3.1 lists the methodologies applied, which I will then briefly describe afterward.

Methodology	**Paper**
Design Science Research	#1, #3, #4
Qualitative Data Analysis	#1, #3, #6
Literature Review	#1, #3, #4, #5, #6 and integrative chapter
Thematic Analysis	#1, #5 and integrative chapter
Quantitative Data Analysis	#6
Formal and Empirical Methods	#3

Table 3.1. Methodologies applied in the dissertation, including the integrative chapter.

3.1 Design Science Research (DSR)

Several papers were design-driven projects [75][76][65][74] to develop specific artifacts, such as in paper 1 [47], an assessment framework for DAO decentralization, in paper 3 [49], a DLT-based trading and settlement system for green bonds, and in paper 4 [51], a compliance reporting mechanism using DLT. This approach combined theoretical insights with practical problem-solving to create design artifacts that address real-world challenges. The core of design-driven research concerns creating innovative technological solutions and rigorously evaluating them within their intended contexts using the iterative design process [75], whereby initial prototypes undergo continuous

refinement based on stakeholder feedback and performance evaluations. In examining green bond trading and the regulatory aspects of DAOs, we merged economic theories with legal considerations and regulatory requirements to drive the design, which was important to understanding the broader implications of blockchain and DLT across economic systems and regulatory environments.

3.2 Qualitative data collection

The research in papers 1 [47], 3 [49], and 6 [52] facilitated dialogue between technology developers, legal experts, economists, practitioners, and cultural theorists, showcasing the importance of interdisciplinary collaboration in navigating and shaping the future of decentralized technologies. Since each expert brings their own practical experience from working in the field, the method is typically conducted as a within-case analysis to become acquainted with the data, and from there, a preliminary theory is developed, followed by an examination of cross-case patterns [78].

3.3 Literature review

In the IS literature, a whole range of literature reviews are used [79][80]: Narrative reviews, Scoping reviews, Meta-narrative reviews, Theoretical reviews, Meta-analyses, Meta-ethnography reviews, Meta-syntheses or qualitative meta-analyses, Critical reviews, Realist reviews, Conceptual reviews, Problematizing reviews, Epistemology of literature reviews, Knowledge synthesis methods, Interdisciplinary and transdisciplinary reviews, Innovative methods of conducting literature reviews, and more. A literature review was undertaken in papers 1 [47], 3 [49], 4 [51], 5 [38], and 6 [52] to guide the research question. For this final integrative chapter, aiming to create an assessment framework for DAOs in digital finance, we use what is probably best described as an 'extending review.' An extended review summarizes existing data and develops new, complex constructs by building upon the existing literature, thereby facilitating theory creation. Such reviews, which can vary depending on the literature type, often involve identifying and elevating concepts from primary to more complex levels. This process allows for integrating and comparing different studies, thereby fostering the exploration of broad hypotheses and theories. Typically conducted using qualitative or mixed-method approaches, extending reviews are particularly conducive to developing theoretical frameworks [80].

3.4 Thematic analysis

Thematic analysis [70] was employed to explore and understand the reality of DAO decentralization and suitability in papers 1 [47] and 5 [38] through interviews and a literature review. This method aimed to identify the core characteristics of DAOs and establish decision criteria for their suitability. The analysis followed the six phases proposed by [70]: (i) familiarizing with the data, (ii) generating initial codes, (iii) searching for themes, (iv) reviewing themes, (v) defining and naming themes, and (vi) producing the report. Paper 6 [52] uses generative AI to classify and label off-chain chats, which could be viewed as a transformative approach to thematic analysis.

3.5 Analytics

In paper 6 [52] we classified datasets comprising over 180.000 chats, employing a robust analytics and methodological framework leveraging a Large Language Model (LLM) via OpenAI's API, using a technique similar to a knowledge distillation approach [81]. The process began with data collection and rigorous cleaning to ensure quality and relevance. We then staged the data and applied tokenization to prepare it for ingestion into the LLM. Utilizing zero-shot and few-shot learning techniques, we generated additional data samples and verified with user feedback to ensure accuracy and representativeness. This enriched dataset was used to fine-tune a series of classification models tailored for specific tasks such as community moderation, member contribution assessment, and sentiment analysis. These models enabled sophisticated, automated insights and actions, enhancing the overall effectiveness of our community management and engagement strategies while at the same time allowing for robust scaling and reducing agency costs by 95 pct. This interchapterallowed for

analysis not just of technological implementation but also its societal ramifications and potential for fostering community engagement and shared narratives.

3.6 Formal methods

In developing a new distributed ledger platform (paper 3 [49]) aimed at disrupting traditional capital markets, we employed a combination of formal methods, i.e., mathematically based techniques used for the specification, development, and verification of software and hardware systems, and empirical techniques, i.e, approaches that rely on observation, experimentation, and data collection to understand and analyze phenomena to ensure the robustness and efficiency of our system under the overall DSR approach. We specified system components using formal languages and verified finite-state models against these specifications to ensure compliance and correctness. Additionally, we leveraged logic and proof assistants to validate the algorithms at a foundational level. Complementing these formal approaches, we adopted empirical methods like systematic experimentation and observation to refine the particular algorithms tailored for specific functionalities such as trade monitoring. Benchmarking was integral to our process, providing critical performance metrics that guided iterative improvements and optimization efforts, ensuring our platform met the highest performance and reliability standards.

3.7 Integrative chapter method

For the research question covered in the integrative chapter chapterof the dissertation, we use thematic analysis [70] to map items from the previous work, complemented by additional literature, to design a framework artifact for assessing DAOs and DeFi protocols 'fit' with a regulated financial service offering [82]. We acknowledge that globally, there is still a lot of regulatory uncertainty about how different service offerings around crypto assets are or will be treated. Still, with MICA coming into effect in the EU as the first major regional attempt to regulate crypto, it will likely inform many other markets looking to regulate it. Hence, MiCA informs the framework artifact we develop to analyze the suitability assessment from a regulatory, socio-technical, and practical perspective. The framework artifact is then evaluated based on three prominent DeFi protocols.

3.8 Methodological reflections

Across papers 1 [47], 3 [49], 4 [51], 5 [38] and 6 [52], qualitative research methods (thematic analysis, semi-structured interviews, and workshops) are prominently used. Maintaining consistency and rigor in data collection and analysis procedures is critical in such projects. We acknowledge the risk of researcher bias and subjectivity and ensure qualitative rigor by separating roles in the data collection vs analysis [83]. For thematic analysis, we conduct within-case analysis to gain familiarity with the data and generate a preliminary theory and then examine the data for cross-case patterns, moving from inductive to abductive approaches to classify groupings while remaining open to new theoretical insights [84]. For interviews, we used interview guides [85]. As DAOs and DeFi are new concepts, we supplement academic literature reviews with a grey literature search, following the guidelines proposed by [86].

For design science research, iterative feedback loops are important to ensure the artifacts meet stakeholder requirements. In particular, paper 3 [49] was extensive in the feedback process from a regulatory sandbox, where multiple iterations we designed, tested, and discussed with regulators, almost like action research [87], although we followed the DSR process [88]. In the DSR projects (papers 1 [47], 3 [49] and 4 [51]) we did not experience issues managing stakeholder expectations or maintaining engagement over extended research periods.

Ethical considerations are critical in data collection and modeling, especially when conducting interviews and handling sensitive data. For the research covered in paper 6 [52] we scraped and collected many thousands of chats from online gaming communities. Here, we used a data consent form to comply with GDPR requirements for research projects. Utilizing OpenAI's GPT-3 API was ideal due to its diverse model offerings and the ability to prototype cheaply, postponing significant expenses until production. The GPT-3 models are also well-suited for zero-shot learning, which we

used to create an initial dataset, where the scraped data was not sufficiently granular or representative for modeling, which was then refined by human curators for iterative model finetuning, replicating a highly efficient empirical taxonomy development process. We anonymized all data to shield privacy before ingesting it into OpenAI's API.

Across several papers, we used mixed-method approaches, such as combining scoping reviews with thematic analysis for large language models with human curation of data: mixed methods are increasingly acknowledged by IS scholars as an effective way to understand sociotechnical phenomena [69] in our case the emerging and evolving DAO concept. Managing and integrating data from various sources and methods is challenging but manageable using structured approaches.

Another challenge we encountered was how to design and present research. In paper 6 [52] we experienced the multidisciplinary challenge of assessing cultural production, transmedia storytelling, generative AI, and ethnographic analysis to understand culture in pseudonymous communities, exemplified through a gaming study, and how to control cultural production when hyperscaling. This presents unique challenges in both design and presentation. Combining methodologies from diverse fields requires a comprehensive understanding of each discipline's theoretical frameworks, methods, and standards. Designing a study that effectively integrates these varied approaches involves careful planning to align objectives, methods, and outcomes across disciplines. This complexity not only leads to difficulties in maintaining methodological rigor and coherence but presenting such multidisciplinary research in a way that is accessible and persuasive to diverse academic audiences is challenging, as each discipline has its jargon, conventions, and expectations, which must be navigated to ensure clarity and impact.

In conclusion, a multidisciplinary and mixed methods approach is appropriate for DAO and DeFi research. Still, methodological rigor, ethical considerations, and adaptability are needed to conduct high-quality research in a rapidly evolving field.

In this dissertation, we reflect that the integrative approach across the papers contributes to a deeper understanding of the studied phenomena and provides a robust foundation for future research.

4. Background

The following chapterintroduces the core concepts, starting with why decentralization is important in financial services. We then briefly introduce the concept of blockchain technology, including the technical attributes and evolutionary paths of blockchain; DeFi and distributed technology in finance; and DAOs in an organizational theoretical perspective to prepare the reader for later sections, which dive deeper into the details of DAOs in DeFi and how to assess their suitability in regulated financial services.

4.1 Decentralization and compliance

Financial services involve the transactions required to obtain financial goods. Such transactions are inherently contractual, undertaken by actors with legal capacity. When examining the theory and practice of financial regulation and the approach that regulators take to compliance and enforcement, the analysis begins with what is known as the *responsive regulatory theory* [89]. This theory posits that regulators are most effective when they use a tiered enforcement strategy, starting with compliance-oriented methods for addressing wrongdoing and resorting to sanctions only as a final measure when other compliance efforts have failed.

Regulating and enforcing financial service provisions relies on the existence of valid agreements between identifiable parties. In finance, this typically means legal persons with legal capacity who are capable of fulfilling defined financial obligations. For regulation to apply, subjects must, therefore, be identifiable and have engaged in valid agreements for service delivery; specifically, a legal person must have made a binding declaration of intent to provide a regulated service, a legally enforceable agreement.

Authorities cannot enforce laws and regulations if a system operates in a decentralized and anonymous manner, with no central entity controlling participation and no one to hold accountable, as discussed in detail in paper 1 [47], 2 [48] and 5 [38].

4.2 Blockchain

Blockchain is a specific type of DLT that is decentralized and where transactions are recorded with immutable cryptographic signatures so that a current block always points to the hash of the previous block, ensuring tamper-proof recording and resource preservation. Its main role is to maintain an append-only ledger that can only be added to within a peer-to-peer network utilizing a consensus mechanism to validate transactions [90]. Permissionless blockchains, characterized by their decentralized nature, maintain a single, global version of a database and ledger replicated across the network and visible to all participants [91]. These blockchains are open, allowing anyone to join, leave, and read and write freely without centralized authorization. Figure 4.1 illustrates a blockchain consisting of blocks and transactions, where each block is cryptographically linked to the previous one by referencing its hash. Each block contains multiple transactions, resulting in an immutable database that records transactions in chronological order.

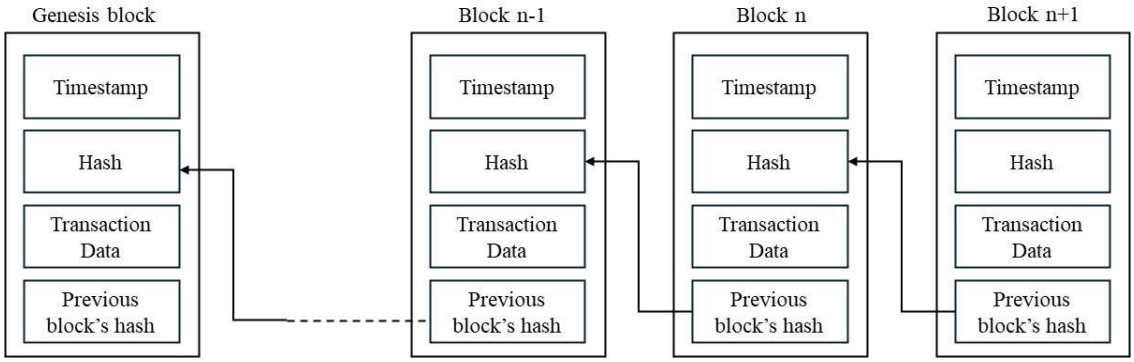

Figure 4.1. Blockchain and block transactions.

When Satoshi Nakamoto created the Bitcoin blockchain in 2009 the key objective was to bypass mediation in payments. E-commerce was then, as it still is today, heavily dependent on financial institutions as trusted third parties to process electronic payments, but this trust-based system has high mediation costs, paper 4 [51], and is still unable to conduct completely non-reversible transactions [92].

Key blockchain primitives (basic data type or operation provided by a programming language that serves as a foundation for building more complex constructs) include cryptographic hash functions, digital signatures, public/private key pairs, consensus algorithms, and tokens. Cryptographic hash functions, such as SHA-256, take an input and return a fixed-size string of bytes, ensuring data integrity, creating digital fingerprints, and securing the linking of blocks in a blockchain. Digital signatures are cryptographic schemes that provide authentication, data integrity, and non-repudiation, allowing users to sign transactions and verify the authenticity of messages. Public/private key pairs, used in asymmetric cryptography, facilitate encryption, decryption, and the creation and verification of digital signatures, thereby securely managing identities and controlling access to digital assets. Consensus algorithms, including Proof of Work (PoW) and Proof of Stake (PoS) enable nodes in a distributed network to agree on a single version of the truth, ensuring the integrity and consistency of the blockchain. Tokens represent assets or rights on the blockchain, such as cryptocurrencies, utility tokens, security tokens, and non-fungible tokens (NFTs), facilitating transactions, access to services, and ownership representation.

Scholars [93] suggest that the characteristics of blockchain-based governance systems should be evaluated within the context of specific business goals. Hence, for decentralized apps (dApp) to function properly, the underlying blockchain protocol should include four basic security properties: (i) consistency (all nodes see the same data at the same time, well, almost), (ii) availability (the system is

operational and can respond to read and write requests even if some nodes fail), and (iii) integrity (trustworthiness of the data stored on the blockchain), which, together with an appropriate consensus mechanism ensures collusion resistance through (iv) decentralization, so that no group can gain an unfair advantage or manipulate the system [94]. An important instantiation of permissionless blockchains besides Bitcoin [95] is Ethereum [1], which hosts more than 60 percent of DeFi applications [96].

Smart contracts are automated scripts that execute predetermined business functions. Financial services or products built as smart contracts operate on their own, autonomously, without needing oversight or intervention from their developers, thanks to the deterministic nature of the blockchain they run on [60]. This ensures that if the blockchain functions, the smart contract will consistently execute its business logic without conditions or reversibility (paper 2 [48]). Typically, these contracts execute instructions that enable users to lend, swap, or engage with 'tokenized' financial assets [6].

The concept of blockchain, as chronological sequences of hashed data, was initially developed by cryptographers more than 30 years ago [97]. The envisioned applications back then were modest, seeing the technology primarily as a means to timestamp digital documents to ensure their authenticity. The authors also developed the world's oldest 'blockchain,' publishing their cryptographic hash for their timestamping services (surety.com) weekly since 1995 in the New York Times, making it impossible to tamper with the timestamp itself, as detailed in Figure 4.2 below.


NOTICES & LOST AND FOUND
(5100-5102)
Universal Registry Entries:
Zone 2 -
dS8492cgVOFAoP9kyE1XzMOrQ
HgEwzkVbVafNvIkUz99qvq8/ME
p5v9EFSG8XxzMBalGQQ==
Zone 3 -
JnFCg+HCmvhj8GmmUP7VZna71
NgZup/RfuKUQNzCHWXMuqLK
durxHQV5pSHLqBGPRIv+mg==
These base64-encoded values represent the combined fingerprints of all digital records notarized by Surety between 2009-06-03Z 2009-06-09Z.
www.surety.com 571-748-5800

Figure 4.2. Example of Surety's cryptographic hash from the New York Times

Bitcoin [92] introduced the world to the modern concept of blockchain, a permissionless peer-to-peer financial system based on blockchain, enabling online payments to be transferred directly between individuals, bypassing the need for intermediaries like banks and with no central control. Ethereum [98] introduced an enhanced type of smart contract, which included an application layer, that enabled programmable money, and the concept of decentralized finance (DeFi), a blockchain-powered peer-to-peer financial system, took off, envisioning a non-custodial, permissionless, transparent, and potentially more efficient financial system akin to the principles outlined in the original Bitcoin whitepaper [99]. From a financial policy perspective, a key challenge with permissionless blockchains is the pseudonymous nature of the system, which prevents the effective identification of actors and, hence, enables illicit finance. Another challenge from a capital market perspective is the lack of real-time finality, given the consensus mechanisms are probabilistic [49].

In the context of DeFi and DAOs, blockchain's main characteristics can be summarized as per table 4.1 (here focusing on permissionless blockchain):

Property	**Description**	**Literature**
Decentralized	A blockchain is a peer-to-peer system that is technically and organizationally distributed and decentralized.	Papers 1 [47], 3 [49], 4 [51], and [10], [90]
Immutable	A blockchain utilizes cryptography and incentive mechanisms to establish a secure and unchangeable distributed ledger, serving as the definitive source for the sequence of events.	Paper 3 [49], and [90]
Transparent	Transactions are transparent and accessible to anyone.	Paper 3 [49], 4 [51],

		and [100]
Pseudonymous	Transactions are associated with wallet addresses, not individuals.	Paper 1 [47], 5 [38], 6 [52], and [90]
Finality	A transaction either succeeds or fails, is timestamped, and is confirmed, but it is only irreversible once finality is achieved (either probabilistic or deterministic).	Paper 3 [49], and [90]
Trustless	Participants do not need to trust each other or any central authority to ensure the integrity and validity of transactions. Instead, trust is placed in the underlying technology, protocols, and consensus mechanisms that govern the blockchain.	Paper 1 [47], 2 [48], 5 [38], and [100]–[102]
Resource preservation	A blockchain records events and guarantees a no-double-spend property in accounting.	Paper 3 [49], and [10]

Table 4.1. Permissionless blockchain characteristics.

4.3 Decentralized Finance

Decentralized Finance (DeFi) applications are financial tools developed using "smart contracts" that primarily function on open blockchain technology. DeFi broadens the idea of non-custodial transactions to include sometimes complicated financial activities, offering participants increased control and accessibility (paper 1 [47]). They are multi-layered architectures with blockchain in the lowest (settlement) layer. The goal of DeFi is to function in a decentralized and disintermediated way, removing the need for traditional financial intermediaries and centralized institutions. As DeFi removes intermediaries and is open and accessible, it fosters innovation and competition.

According to [23] the DeFi ecosystem accumulated a total value locked (TVL) of more than USD 180 Bn in assets at its peak in late 2021, approximately six pct of the crypto market total market cap of the app USD 3Trn. The sector stands at around USD 100 Bn when writing this dissertation. In the aggregate, global financial services have a market cap of USD 35Trn [103] with around USD 461Trn in assets managed by the end of 2022 [104]. So, while DeFi is still only a fraction of financial markets, DeFi represents a transformative shift, leveraging blockchain technology to enable peer-to-peer financial transactions and services outside traditional financial intermediaries.

Some scholars define DeFi as “a competitive, contestable, composable and non-custodial financial ecosystem built on technology that does not require a central organization to operate and has no safety net.” [105], although it is unclear why the safety net is relevant to the definition, this could be programmed into DeFi as a decentralized concept, and DeFi would still be DeFi. Others propose a more neutral definition: “A DeFi protocol is a decentralized application that facilitates specific financial service functions defined and implemented by a set of protocol-specific code accounts,” where code account means a smart contract [106]. Yet others [99] refrain from defining it, as it is an evolving industry that is continuously changing and finding new product-market fits. Yet, as an evolving industry, “DeFi generally denotes financial products, services, activities, and arrangements that leverage distributed ledger or blockchain technology, including self-executing code (smart contracts or a collection thereof)” [107].

Like modern software programs, DeFi protocols adhere to the "abstraction principle," which involves organizing well-defined functions into multiple layers of abstraction (compositions), with each layer utilizing the functionality of the layer directly below it. At the core is the on-chain execution and recording of transactions on a permissionless blockchain, the settlement layer, through the composable and interface layers [105] delivered through autonomously executing software.

DeFi consists of four primitives [99]. ‘Smart contracts’ are the first primitive. Smart contracts are programmable agreements deployed on a blockchain. The terms of the agreement are encoded in software and automatically enforced by the underlying protocol once triggered by predefined conditions. Each DeFi protocol comprises one or more smart contracts providing specific financial services, such as lending, borrowing, trading, or yield farming. Although referred to as self-executing,

these contracts typically require an external agent, such as a human, oracle, or another system, to initiate the execution process [1]. DeFi's second primitive is financially incentivized external entities called 'keepers.' Keepers are automated agents that manage state updates and perform various tasks to ensure the system's smooth operation by executing predefined actions under certain conditions. They automate routine tasks that would otherwise require human intervention, thereby maintaining the efficiency and reliability of decentralized protocols. In many DeFi platforms, keepers play critical roles in arbitrage and liquidation processes, such as monitoring loans and automatically liquidating positions when collateral levels drop to maintain platform solvency. Keepers often interact with the third primitive – 'oracles' to update prices on decentralized exchanges and lending platforms, ensuring accurate price feeds essential for trading, lending, and borrowing. Blockchain oracles are agents that connect blockchains to external systems as a mechanism for importing off-chain data into the blockchain virtual machine so that it is readable by smart contracts. For stablecoins and synthetic assets, keepers help maintain the peg by engaging in arbitrage or buying and selling assets to keep the value stable. Additionally, keepers implement protocol upgrades and changes based on governance decisions, executing community-voted changes to keep the protocol up to date.

The third primitive, 'oracles,' supplies critical data feeds necessary for various DeFi operations like trading, lending, and borrowing. Oracles operate by sourcing, verifying, and delivering data to smart contracts, enabling these contracts to execute based on the received information. They are vital for preserving the integrity and functionality of DeFi protocols, as smart contracts cannot directly access external data.

A fourth and final primitive is governance. Governance involves changing the parameters that define interaction between participants within a system, either algorithmically or through agents. Although a regulator may well assess decentralization point-in-time, as they assess the compliance requirements at the time when a regulated activity is undertaken, many DeFi protocols start with a centralized governance model, often led by a "benevolent dictator" or a small council with control over governance parameters, with an intention to eventually decentralize. This decentralization is typically achieved through issuing governance tokens that allow holders to vote on and propose updates to the protocol. These tokens signify ownership in the protocol. Often, a DAO is responsible for the protocol's stewardship, but sometimes, there is no formalization, which we will return to later.

Scholars [105] have suggested there are additional primitives – capital providers (liquidity providers) and users, both in governance (investors) and in service offerings (traders, arbitrageurs). As primitives are essential components to make a system work, including these participants acknowledges that the ecosystem's functionality relies not only on technological components but also on the active involvement of different types of agents.

- Capital/liquidity providers supply funds to liquidity pools, enabling trading, lending, and borrowing within DeFi protocols. From a supply-side perspective, their role is critical for functioning decentralized exchanges and other financial services.
- DeFi users are individuals or entities that interact with DeFi protocols to perform various financial activities such as trading, borrowing, lending, and earning interest. They are essential for the demand side of the ecosystem.
- Governance users hold governance tokens and participate in the decision-making process of DeFi protocols. They vote on proposals affecting the protocol's rules, upgrades, and overall direction. Their involvement is key to the decentralized governance model that many DeFi protocols aim to achieve.

In its ideal form, DeFi extends the innovation of non-custodial transactions to complex financial operations akin to assembling Lego blocks, albeit with adherence to underlying (blockchain) protocol collateralization rules and assuming these underlying chains possess blockchain's general consistency, integrity, and availability security properties. Central to DeFi is the use of permissionless blockchain platforms that support smart contracts, which facilitate automatic execution, control, and documentation of actions according to the terms programmed into the contract. DeFi is characterized by its decentralization, which reduces reliance on centralized financial institutions. It operates

permissionless, allowing anyone with an internet connection to access its services without requiring approval from a central authority. This openness contributes to its transparency, with all transactions publicly recorded on the blockchain for verification. Additionally, DeFi is becoming noted for its interoperability, where different applications are designed to integrate seamlessly through 'wrapping', enhancing functionality and user experience. There are four key attributes in DeFi. [99], table 4.2.

Attribute	Description
Non-custodial	Applications can only access information presented on a blockchain, and participants have full control over their funds via non-custodial wallets.
Accessible	Open to any user and open to integrate with any other application without being censored or blocked by a third party or intermediary, making it highly competitive.
Composable	It is highly interoperable and built on underlying blockchain smart contract templates, which allow the design of new services without needing approval by any authority, making it highly innovative.
Transparent	Open source and with intrinsic logic, anyone can audit the state of the system at any point in time.

Table 4.2. DeFi attributes.

While DeFi promotes innovation with automated loans, complex financial products, and dynamic trading strategies and aims to include those excluded from traditional banking, it also faces high risks. The reliance on smart contract security, which can be vulnerable to exploits, and the regulatory uncertainties surrounding DeFi pose challenges. In addition, the inherent market volatility can lead to substantial financial losses. A DeFi protocol delivers one or more financial services to economic agents, implementing these services as program functions within smart contracts. Building on [97][103] DeFi applications cover the following main categories at the time of writing this dissertation, though several DeFi protocols offer more than one set of applications, cfr. the composable nature of smart contracts, table 4.3:

DeFi application	Description
On-chain asset exchanges	On-chain asset exchanges (including DEXs) aim to facilitate asset trading with varying complexity (AMM vs. order book DEXs) their core goal remains relatively specific – to enable secure, decentralized trading. Scholars have suggested that AMMs could save billions of USD annually for equity investors in traditional capital markets [108]. Examples: Uniswap, Sushiswap, Balancer
Loanable funds markets for on-chain assets	Loanable funds markets for on-chain assets (DeFi lending protocols) handle collateralized debt/loans, (re)staking, and yield farming based on risk assessments, collateral management, and sometimes complex liquidity algorithms to manage liquidations of collateral breaches. Examples: Aave, Compound, Yearn.Finance, Harvest Finance, MakerDAO.
Stablecoins	Non-custodial stablecoins (e-money tokens or asset reference tokens in MICA terms) aim to maintain stability against a peg, which can be complex given the need for managing reserves and responding to market dynamics. Examples: DAI (MakerDAO), RAI (Reflexer Labs), sUSD (Synthetix)
Portfolio management	Portfolio management (including crypto or real-world assets) involves evaluating multiple assets, making investment decisions, and potentially adjusting strategies based on market conditions. Examples: Set Protocol, TokenSets.
Derivatives	Derivatives (including synthetic assets, futures, perpetual swaps, and options) are complex financial instruments with varied underlying assets, leveraging, and hedging strategies. Examples are Synthetix, Opyn, Hegic, and dYdX.
Mixers	Privacy-preserving mixers have a clear and specific primary goal: to enhance transaction privacy. Examples are Tornado Cash and Wasabi Wallet.
Insurance	Insurance (including decentralized insurance marketplaces) involves assessing risks, pricing policies, managing claims, and maintaining liquidity. Examples:

	Nexus Mutual, Cover Protocol.
NFT marketplaces	Platforms for creating, buying, and selling non-fungible tokens (NFTs). In some markets, NFTs are considered securities by regulators; in other markets, they are unregulated unless fractionalized, making them fungible and may be treated as crypto assets. Examples: OpenSea, Rarible.
Services	This broad category includes governance, identity, Oracle, and other infrastructure services supporting DeFi and non-DeFi applications. Examples are Chainlink (Oracle), Compound Governance, Snapshot (Governance), Bloom, and BrightID (Identity).

Table 4.3. DeFi applications.

Some stakeholders suggest that crypto markets and permissionless blockchain will impact every aspect of finance [109]. Yet, it seems more likely that the regulation of the underlying technology and its enforcement will determine this impact [110]. It is also likely that this impact will come through tokenization based on alternative technology, such as permissioned DLT [111], rather than permissionless blockchain, which suffers from finality latency due to probabilistic consensus methods (paper 3 [49]).

To the extent DeFi actors meet the decentralization test, the future of DeFi seems positive, with innovations aiming to replicate and improve traditional financial services. The sector's development will likely be influenced by its integration into broader blockchain ecosystems, adaptations to emerging regulatory frameworks, and technological advancements. This movement toward a more open and efficient financial system, perhaps a decentralized version of the Finternet, promises enhanced inclusivity but also requires careful consideration and potential regulation to mitigate associated risks.

Many DeFi protocols are organized around DAOs that leverage the same smart contract properties to create rules-based organizations where decisions are coded. Other protocols are on a journey towards decentralization but are still dominated by central actors. Yet other protocols do not claim to be DAOs but appear highly decentralized in some respects and have governance organized like DAOs (Uniswap, Compound Finance), as we will touch upon later.

4.3.1 The challenge of non-compliance for DeFi

As an emergent financial sub-sector, DeFi is still young and a ‘bit of the Wild West,’ but as it matures and gains importance, actors in DeFi must also consider regulation. To demonstrate the challenge of non-compliance for DeFi, we use the case of Tornado Cash.

The Tornado Cash case has developed substantially since the research undertaken for paper 2 [48]. Most recently, one of the founders was sentenced to five years in jail by a Dutch court in May 2024 [112] for laundering more than USD 1Bn. The case is specific to money laundering, which is a serious offense but topical to the crypto market given the unregulated and decentralized nature of crypto services. The case is processed in parallel in the US against the co-founders of Tornado Cash [113]. It provides some direction for the level of decentralization required to avoid being held responsible for compliance in financial services in both the US and the EU.

Tornado Cash is a decentralized protocol that facilitates anonymous cryptocurrency transactions using ‘pools’ managed by smart contracts on the Ethereum blockchain. These pools accept deposits and enable withdrawals, breaking the link between deposit and withdrawal addresses to ensure user anonymity. Each pool operates under a smart contract, autonomously executing predefined commands when specific conditions are met. This decentralized infrastructure makes it technically impossible to take these smart contracts offline. The protocol offers pools in fixed denominations (0.1, 1, 10, or 100 Ether), enhancing anonymity by standardizing transaction amounts. The user interface (UI) is hosted on the InterPlanetary File System (IPFS). This decentralized file system ensures the UI cannot be offline, maintaining access to Tornado Cash. Tornado Cash does not require personal information for transactions. It does not implement Know Your Transaction (KYT) checks, employing zk-SNARK technology to enable users to prove ownership of information without revealing it. It is a non-

custodial protocol, meaning users retain full control over their deposited cryptocurrency and use a deposit note for withdrawals. Users can withdraw funds directly to a wallet or via a 'relayer.' Relayers are external systems that execute transactions on behalf of users, ensuring privacy by preventing traceable transaction trails. The relayer pays transaction fees from the withdrawn amount, further obscuring the user's identity.

Regarding organizational decentralization, Tornado Cash transitioned to a DAO in December 2020, purportedly transferring governance to the community. However, the three original developers/founders and two investors retained substantial control by distributing governance tokens. The Dutch court found that the original team continued influencing decisions and developments, indicating that true organizational decentralization was not achieved.

Technically, the smart contracts of Tornado Cash are immutable and autonomously functioning on the Ethereum blockchain, making them technically decentralized. This decentralization ensures that the core functionalities cannot be altered or taken offline, independent of the developers' control.

However, although Tornado Cash's service provisions appear decentralized in that they allow for anonymous transactions without intermediaries controlling user funds, the founders' control over the UI was substantial, and they profited from it. Hence, legal capacity was involved in the provision of the services, and the court found that the centralized control of the interface compromised the overall decentralization of the offering, as it could potentially be influenced or altered by the founders.

The Dutch court ruled that Tornado Cash itself engaged in money laundering by concealing the origins and movements of cryptocurrency. The developers' involvement in creating and maintaining the protocol and their substantial control despite the DAO structure placed responsibility for the money laundering activities on them. The court emphasized that the design choices, such as anonymous pools and relayers, facilitated these illegal activities.

Regarding privacy, the defendant wanted to draw a parallel between transactions with cryptocurrency on the blockchain on the one hand and transactions in the banking world on the other. However, the Dutch court found that the developers failed to provide guarantees to protect the integrity of the financial and economic system, as is customary and mandatory in traditional finance (CeFi). This suggests a personal duty of care for founders and developers in designing DeFi applications regarding compliance.

The case exemplifies how the assessment of decentralization in financial services compliance is evolving to several levels:

- Organizational decentralization, where the power and control of the organization governing the technology is decentralized, agents are independent, and no central identifiable agent or group of agents controls decisions or has special privileges.
- Technical decentralization, where the organizational technology's power and control are decentralized, node operators are independent, and no central identifiable agent or group of agents controls the network or has special privileges.
- The financial service, or 'product,' is made accessible to the public in a decentralized manner without identifiable agents or a group of agents controlling or dominating the access/distribution.

This level of decentralization is transformative and informs the supervisory test for enforcement in decentralized finance, acknowledging that regulation does not apply if a financial service that is otherwise regulated is fully decentralized.

4.4 DAOs and organizational theory

Not all projects that began as DAOs are suitable for such a structure, as the chosen governance model may not align with business objectives [114]. This resonates well with traditional organizational theory, which states that business objectives, the operating environment, and product-market fit influence risk management practices.

Where conventional organizational structures, often likened to "pipes," undertake the conversion of raw materials into products or services for consumer consumption, the digital era has shifted towards platform-based organizations. Rather than producing goods or services, these platforms foster digital connections between producers and consumers. Scholars in organizational design [115] categorize these into exchange platforms, which enable direct producer-consumer interactions, and maker platforms, which connect one producer with thousands of consumers. The architecture of such digital organizations is marked by fewer assets, accelerated information flows, and diminished hierarchical structures. Nonetheless, despite digital platforms' promising agility and efficiency, they encounter challenges in maintaining a corporate culture within a less controlled environment, necessitating a strategic focus on cultivating a constructive organizational culture.

Although there are elements of blockchain governance affecting DAOs directly through their technology stack, most DAO research focuses more on experimental and human-centered aspects than blockchain governance, requiring legal, economic, and organizational understanding [42][43][146].

The concept of DAOs advanced significantly with Ethereum [1] and how blockchain could be used for more than money, to create “long-term smart contracts that contain the assets and encode the bylaws of an entire organization” [98]. This new format allowed a more sophisticated and multifaceted approach to contractual arrangements, replicating a wide range of organizational structures and offering a choice between traditional corporations and those digitally constituted via smart contracts. With this development, DAOs became more than just unique online communities; they now had the potential to shift substantial institutional frameworks from traditional settings to the digital realm, integrating law, economics, and computer science.

Although the future prominence of DAOs as organizational forms is uncertain, the growing significance of them is evident [117].

DAOs can exhibit characteristics of organizations, open-source communities, online communities, and digital marketplaces, but their structure and function vary based on their specific goals and governance models. First, DAOs are like traditional organizations in that they often have a defined mission, structured governance, and a membership that collaborates toward common goals. Like corporations or nonprofits, DAOs can manage assets, enter contracts (including smart contracts on a blockchain) or directly as unincorporated partnerships or through legal wrapping, and make collective decisions based on member votes. However, DAOs differ in their decentralized nature; there should be no central authority or hierarchical management, a key characteristic of many organizations. Second, many DAOs share similarities with open-source communities, especially in terms of collaboration, fluid working practices, and governance models [118]. DAOs often manage or govern open-source software projects, making the alignment with open-source communities quite strong.

[119] suggest that DAOs are more akin to online communities. Both DAOs and online communities consist of individuals engaging in social interactions, united by a shared objective, adhering to interaction-guiding policies, and supported by computer systems for their social exchanges. Yet, DAOs also differ from those communities because they have more structured governance mechanisms and distinct token economics that allow for formal decision-making and financial transactions, which is typically not present in casual online communities.

Digital marketplaces are designed to facilitate buying and selling between multiple buyers and multiple sellers. They differ distinctly from DAOs by only providing a structure where goods, services, or digital assets can be listed, discovered, and traded. DAOs, on the other hand, leverage blockchain for the creation of decentralized ecosystems that a community can govern [120]. Like open-source communities, DAOs differ from digital marketplaces by operating under the constitutional rules and collaboration patterns defined by stakeholders. DAOs also differ from digital platform organizations, operating much more independently using token economies and fluid work practices, as pointed out by [118].

With its unique characteristic of decentralized governance, some scholars, building on [54], suggest that DAOs are potentially a fourth type of organization alongside the (i) traditional company, (ii) cooperatives, and (iii) the free market [121]. Other scholars suggest it is perhaps the underlying

blockchain technology that is the new institutional mechanism [55], not the application, where DAOs belong in the technology stack.

When it comes to the theoretical context of organizational design theory [115], as explored by [37], a DAO is a digital-first, fluid network form of organizing that presents a distinct model that diverges significantly from traditional organizational structures. DAOs typically feature a low hierarchy of authority with equal voting rights, supporting a decentralized organizational structure, thereby maintaining low centralization through voting mechanisms that promote decentralized decision-making. The specialization within DAOs is considered a medium as it demands the implementation of new automated processes. Formalization is high, characterized by highly formalized processes that facilitate the automatic execution of organizational tasks. Professionalism, as in how well-trained members of an organization must be to participate, is not high, as anyone can have great influence without a high level of education. This naturally depends on the scope of a DAO's mission, as some DAOs deliver complicated financial services in DeFi, where competence to manage risks should be comparably high, as in other financial institutions; decentralization does not remove financial market risk. The personnel ratio in DAOs is typically low, reflecting a lean operational model. Size can be extensive, potentially as vast as the blockchain network itself. However, the cost of coordinating collective action can become a limiting factor, especially if the DAO pursues a broad mission. The organizational technology is intensively structured around blockchain technology, which forms the backbone of the organizational structure. DAO environments are dynamic and driven by the cryptocurrency sector's rapid technological and organizational changes.

Whether a network or powerbase is decentralized or distributed has created some confusion since the concepts were initially introduced into network engineering in the 1960s [122], where decentralization was approached from the perspective of redundancy, distinguishing networks by the number of failed nodes needed to disrupt communications – a single node in centralized networks, a few nodes in decentralized networks, and a majority of nodes in distributed networks.

More recently, Vergne [123] recognized that from an organizational perspective, and, hence, in the context of DAOs, communication and decision-making are critical for the functioning of organizations. Still, they form part of two distinctly different systems that are not related to redundancy as such: (i) In the presence of a managerial hierarchy to support decision-making, complexity is about distributing decisions. It increases mainly as a linear function of membership size, representing a vector or continuum in a distributed vs. concentrated decision-making space. This is not a question of redundancy but about humans' cognitive capacity. (ii) Organizations gather unstructured data from their environment and structure it to make it understandable and into information by adding meaning and perspective to the data, eventually becoming useful as knowledge. This question of coordination can be either centralized or decentralized, hence representing a vector or continuum in a centralized vs. decentralized space of information coordination. Aside from the question of technical decentralization or distribution, viewing organizations as coordinated communication systems, the "D" in DAO can, therefore, best be delineated into the decision-making process as either concentrated or distributed, which is mainly a question of size, and information coordination as a question of knowledge management and consultation process, being controlled either centralized or decentralized.

Stereotyping organizations in this continuum, Vergne suggests four types:

1. Centralized-concentrated (Ce-Co) organizations are characterized by a central concentration, where members independently organize data gathered from their surroundings and relay it to a decision-maker responsible for its analysis and processing. This resembles a traditional manufacturing company (e.g., a 20th-century automobile manufacturer). In this structure, factory workers collect production quality and productivity data but pass this information to a central quality control department or manager who makes key decisions regarding process changes.
2. The decentralized-concentrated (De-Co) organizations differ from the former by the frontline members. They are also tasked with information integration yet are still subject to a manager's decision. This resembles a retail chain store (e.g., a supermarket chain), where

individual store managers gather and integrate information about local market trends, customer preferences, and inventory levels. However, they still follow centralized pricing, promotions, and inventory policies set by corporate management.

3. Centralized-distributed (Ce-Di) organizations increase process efficiency by distributing trust by delegating aspects of decision-making to subordinates through a managerial hierarchy, thus requiring fewer consultation channels. This is akin to a franchise business model (e.g., McDonald's), which is individually owned and makes certain business decisions (hiring, local marketing). Still, core strategic decisions like menu items, branding, and major campaigns are controlled centrally by the corporate office.
4. Decentralized-distributed (De-Di) organizations maximize information integrators while keeping the number of channels needed per integrator to a minimum through clearly defined non-hierarchical consensus protocols. This form of organization, the De-Di, with trust and power being both distributed and decentralized, is likely what most scholars and practitioners think of when considering DAOs operating on public permissionless blockchains with sufficiently distributed decision-making, coordinated through sufficiently decentralized communication [47]. Here, token holders propose and vote on changes (like adjusting stability fees or adding new collateral types in a financial services lending DAO). Consensus is reached through a transparent, decentralized protocol without hierarchical management.

From a technical perspective, a blockchain technology framework can be structured to differentiate structurally between applications and protocols. In this model, each subsequent layer adopts the rules and protocols from the layer beneath it. For example, DAOs, assuming they are primarily based on blockchain, must comply with the protocols of three fundamental layers: the Internet, blockchain, and application layers. This means the restrictions of the blockchain, the internet, and any application-specific limitations bind them and their members. Unlike conventional organizations governed by national laws and legal contracts enforced by a country's legal system, these DAOs can operate more openly and inclusively without geographical or censorship boundaries. Instead, they are governed by a set of mutually agreed-upon rules embedded in an open-source protocol as a (set of) smart contract(s). Changes to these rules or contracts can only be made through a majority decision by its members. Further, when blockchain is the main technology underpinning a De-Di organization, it decentralizes communications by enabling each member to hold an immutable record of the organization's history, including past transactions, protocols, and reward systems. This allows anyone, including any new member, to establish trust by verifying the consistency of these records with a few nodes, after which they can download the necessary open-source software for organizational tasks.

A core proposition of a DAO as an organizational form of choice suggests that trust (and power) is established through distributed decision-making, where anyone can become a decision-maker, coordinated through decentralization, where everyone has equal access to information. Coordination occurs through decentralized (a) algorithmic coordination, (b) social coordination, and (c) goal coordination [124], which in combination, at least in theory, should reduce transaction costs compared to traditional formats of incorporation [56].

Summarizing the confusing and somewhat complicated D-D spectrum and how to assess these empirically, the decision-making process vector (Distributed vs. Concentrated) explores how decisions are made within an organization, focusing on whether this process is widely distributed among members or concentrated in a managerial hierarchy. The information-coordination vector (Centralized vs. Decentralized) manifests itself either in a centralized manner, with centralized control of knowledge management and consultation processes, or in a decentralized fashion, supporting a more dispersed approach to handling information.

DAOs' cultures are open and transparent, reflecting their foundational principles. Daft's framework delineates the unique ways in which DAOs adapt and challenge traditional organizational theories and practices. Table 4.4 shows how DAOs align with Daft's [115]'s design principles, building on Pohl [37].

#	Dimension	Description of DAO in the context of Daft dimension
1	Hierarchy of authority	The organizational structure features a low hierarchy of authority,

		granting equal voting rights to all members.
2	Centralization	Centralization is minimal, utilizing a voting mechanism for decentralized decision-making.
3	Specialization	Specialization is moderate, necessitated by the implementation of new automated processes.
4	Formalization	Formalization is high, characterized by highly structured processes for the automatic and autonomous execution of organizational activities, including voting, treasury management, and reward distribution.
5	Professionalism	Professionalism is low in general but high for the technical team implementing the DAO and for risk management for DeFi DAOs.
6	Personnel ratio	Low, given the flat and fluid nature of DAOs.
7	Size	High, limited by the size of the blockchain network structure blockchain, but constrained as the cost of coordination of collective action increases with size and complexity.
8	Organisational Technology	Intensive, being structured with blockchain technology as the backbone of organizational structure.
9	Environment	Dynamic due to the fast-moving transformation in technology and organization in crypto
10	Culture	Open and transparent

Table 4.4. DAOs in organizational design theoretical context, building on [37].

Regulations are treated in Daft's framework as part of the external environment and in Pohl's analysis as both external and internal, where the internal dimension is the 'code is law' approach captured in smart contract execution and the external as a coercive source of institutionalization of formal structure. We will revert to this in a later section below.

4.5 DLT in traditional finance

New products and competitors generally boost supply in any market, including financial services, by driving down the price of services and promoting financial inclusion in finance. However, this could also threaten the financial system's stability and effective operation if not properly managed.

Keen to prioritize innovation in financial services, the EU Commission introduced a digital finance agenda in 2020 that led to important new regulations in 2022 (paper 3 [49]). These included the DLT Pilot Regime Regulation No. 2022/858 ('DLTR'), effective from 2023, and MiCA, which took effect in June 2024. Both regulations adopt the same definition of DLT but are applied under different legal frameworks. MiCA primarily governs crypto assets that do not qualify as securities. In contrast, securities that are tokenized or digitally represented remain under existing securities laws such as the Market in Financial Instruments Directive II (MiFID II), Market in Financial Instruments Regulation (MiFIR), and the Central Securities Depository Regulation (CSDR), alongside the DLTR. The DLTR specifically facilitates the use of DLT in trading and settlement processes, granting necessary regulatory exemptions for DLT-based operations. The regulatory evaluation of these technologies occurs within a regulatory sandbox, an innovative environment that allows regulators to engage in knowledge exchange, provide oversight and advice directly, and guide the regulatory licensing necessary for integrating new technologies into the financial system.

According to the DLTR, the existing EU financial services legislation was not originally crafted to accommodate distributed ledger technology (DLT) or crypto-assets, and it includes provisions that could restrict or completely prevent the application of DLT in the issuance, trading, and settlement of digital-assets recognized as financial instruments. As DLT could potentially benefit these processes, a new regulation was required to allow new entrants and incumbents to experiment with DLT, subject to a sandbox process to ensure proper regulatory treatment. DLTR defines a distributed ledger as "an information repository maintaining records of transactions synchronized between network nodes using a consensus mechanism."

Interestingly, DLTR does not mandate tamper-evident or tamper-proof recordings, nor does it require technical and organizational decentralization or guaranteed resource preservation, which are fundamental characteristics of blockchain systems [10].

According to [125] the global cost of financial intermediation amounts to over US$5,5 trillion (as in 5,500 billion US$). Over the past couple of years, the Bank for International Settlement (BIS) has published several research papers and surveys on the applicability of DLT and blockchain in finance and capital markets [105], [126], [127]. While the BIS does not regard the crypto market or DeFi in general, it does embrace the concepts of DLT and blockchain.

Permissionless DLT will struggle in many aspects of traditional securities trading and settlement, but permissioned DLT should have a prosperous future in the same environment (papers 3 [49] and 4 [51]). For example, in a recent working paper [17], the BIS presents a forward-looking vision for an interconnected financial ecosystem that mirrors the functionality of the internet, focusing on user-centricity, accessibility, and the integration of various financial services. This future system, the 'Finternet,' leverages technologies for tokenization and introduces the concept of 'unified ledgers' to enhance the range, efficiency, and security of traditional financial services, aiming to foster greater financial inclusion and reduce operational costs. The BIS paper avoids directly referencing established terms such as blockchain, DLT, or DeFi. However, the entire paper concerns DLT and how different DLT-based systems interconnect and allow user-centricity and real-time execution. While this omission seems to be a strategic choice, possibly intended to distance this new vision from the volatile perceptions and regulatory challenges associated with these technologies through DeFi, the BIS does embrace these technologies' technical affordances in traditional finance, hence, the BIS endorses DLT tooling as a critical component of the future rails of finance.

Implementing the Finternet requires establishing a comprehensive legal, regulatory, and governance framework for the markets where it operates. This framework is critical for safeguarding participants and ensuring the financial system's integrity. The BIS calls for proactive collaboration between public authorities and private sector institutions, advocating for permissioned architecture with central banks having a leading role.

A fundamental principle suggested by the BIS is that existing laws and regulations should govern participants and assets in this Finternet so that ledgers and infrastructure do not offer avenues for evading laws or engaging in regulatory arbitrage. Consequently, jurisdictions should not devise a completely new, customized legal framework; rather, the principle of technological neutrality should advise authorities to harmonize the legal treatment of similar financial assets across various venues to the greatest extent possible.

In one fundamental aspect, however, a new regulatory framework is needed: Whether central banks have the authority to issue tokenized central bank money. According to an IMF study, [128] as of 2020, the legal frameworks of approximately 80% of central banks were either ambiguous on this issue or explicitly prohibited central banks from issuing tokenized central bank money. Regardless of whether central banks ultimately decide to issue tokenized central bank money, this uncertainty needs to be resolved, as without a wholesale tokenized central bank asset, the future financial system will have to rely on legacy architecture to settle financial transactions, which would undermine many of the benefits offered by distributed (unified) ledgers. This finding resonates well with what was learned in the DLT regulatory sandbox project (paper 3 [49]).

4.5.1 Regulated finance and DAOs

To exemplify the scope of regulated financial services and DAOs, we focus mainly on the EU regulatory context, where the markets in crypto asset regulation (MiCA) come into effect in 2024. Regulators perceive this regulation as essential to ensure that EU legislative acts on financial services are adapted for the digital age and support an economy that leverages innovative technologies. The regulation aims to promote the adoption of transformative technologies like DLT in the financial sector, which is expected to spur economic growth and create new jobs. Through the legislators' lens, crypto assets, a primary application of DLT, offer significant benefits, including efficient cross-border payments and innovative financing options, especially for small and medium enterprises (SMEs).

Except for anti-money laundering laws, governing the provision of services related to crypto assets was unregulated before MiCA, exposing holders to risks and creating market integrity issues, where the absence of a unified framework could undermine user confidence, hinder market development, and lead to regulatory fragmentation. This is not in line with the EU financial policy objectives, which focus on market integrity, financial stability, and consumer protection, as discussed in more detail in paper 2 [48]. Hence, a dedicated and harmonized framework for crypto assets at the EU level was required to establish clear rules, protect consumers, and ensure financial stability.

Regulated crypto assets and services under MiCA are, broadly speaking, stablecoins pegged to one traditional (fiat) currency or commodity or index (denominated as e-money tokens (EMT) in MiCA) and asset reference tokens (ART) that peg to several of those. Algorithmic coins are also covered to the extent they peg like fully backed coins, i.e., a 'soft' peg to the US$ or € is equally regulated. As mentioned, tokenized securities are not regulated by MICA, nor are non-fungible tokens (NFTs) or tokens required to operate a blockchain, so-called protocol coins, such as ETH, the native coin to the Ethereum blockchain and Bitcoin, the native coin of the Bitcoin blockchain.

In addition to regulating these crypto assets, MiCA regulates crypto asset service providers that are required to establish a robust regulatory framework. In the words of MiCA art 3(15), a crypto-asset service provider (CASP) is defined as a legal entity or undertaking whose profession or business involves offering one or more crypto-asset services to clients in a professional capacity.

An 'offeror' refers to a natural or legal person or any other entity (undertaking), including the issuer, that offers crypto assets to the public. (MiCA art 3(14)).

An 'undertaking' is not defined in MiCA but is usually an enterprise or task involving risk-taking [129], in this context, refers to any verified agent who conducts business covered by the regulation, including corporations, associations, humans, and anyone with legal capacity, including communities and unincorporated partnerships acting with a common purpose.

Generally speaking, activities such as executing customer orders are usually integrations at the application layer in the technology stack of DeFi, not the infrastructure layer, implying a financial services provision regulated under MiCA.

The services in the scope of regulation include the custody and administration of crypto assets on behalf of clients, operating trading platforms for buying, selling, and trading crypto assets, and providing exchange services to convert crypto assets into fiat currency or other crypto assets. It also covers the execution of client orders related to crypto assets, assisting in the distribution of crypto assets, receiving and transmitting client orders, offering personalized advice on crypto-asset transactions or holdings, managing portfolios that include crypto assets on a discretionary basis, and the issuance of new crypto-assets, such as initial coin offerings (ICOs). This ensures adequate protection of consumers and market integrity and provides legal clarity for market participants.

Although traditional financial services usually attribute provision to identifiable entities, challenges arise when users interact directly with smart contracts on conventional blockchains.

Software lacks independent agency and cannot traditionally enter into agreements; instead, in the case of smart contracts on blockchains, it executes the will of those controlling it. Therefore, assessing whether a smart contract's activity is subject to (regulatory license) authorization involves determining if a 'legal person or other undertaking' has given a binding declaration of intent for the activity provision, qualifying them as a legal subject for the performed regulated activity.

Where an identifiable legal person offers regulated financial services, this person usually has complete authority over those activities. This is similar to traditional or centralized finance, aka 'CeFi,' sometimes called 'TradFi.' These services are provided solely through the companies' internal systems, and the legal person can be held accountable by the regulators. Enforcement is possible in case of non-compliance, and in some cases, also directed to the management through accountability regimes, including through fit and proper requirements.

In partially decentralized scenarios (aka ‘CeDeFi’), where regulated services are offered to the public by a legal person in a decentralized manner, a legal person still maintains an element of control, albeit partially or fully, through smart contracts. In this case, the legal person can also be held accountable, and enforcement is possible. But if no legal person can be identified, as is the case of DeFi, there is no subject to regulate and hold accountable.

From a regulatory perspective, an activity is considered decentralized if it is conducted in a manner that prevents any person from controlling it. When a service operates with sufficient decentralization, there is no central authority to hold it accountable, making enforcing regulations impossible. This lack of a controlling entity, both technically and organizationally, means that even regulated activities may proceed without adhering to regulatory compliance, as there is no feasible way to enforce such compliance. This principle is acknowledged in MICA (recital 22), stating that the regulation applies to individuals and entities and to the crypto asset services and activities they perform or control, directly or indirectly, even if those activities are partly decentralized but not fully decentralized. This covers all asset issuers, offerors, individuals seeking trading admission, and crypto asset service providers.

While crypto assets with no identifiable issuer are generally excluded, the regulation covers services provided by crypto asset service providers for such assets. In the presence of systemic risk or infringement of the regulation by a fully decentralized stablecoin, the regulators may, therefore, enforce regulation indirectly via the distribution channels operated by the crypto asset service providers. Conflict arises between decentralization and services defined as finance because the fundamental principles of one are at odds with those of the other: Decentralization implies no central control or single point of accountability, and regulation requires identifiable control points and entities that can be held accountable along the value chain.

Given these principles, we might describe the relationship between DAOs or, more generally, the concept of decentralization and DeFi vs. traditional financial regulation as a structural paradox, as there is fundamental tension when the core structures or defining features of these systems are in opposition. As they are in ‘decentralized finance.’ This is further exacerbated by the general principles of ‘same activities, same risks, same rules’ and of technology neutrality, where DLT and blockchain enable activity without agency, which is rather technology-specific, as discussed in more detail in paper 2 [48] and the discussions earlier around the Tornado Cash case.

5. DAO taxonomy

Smart contracts, deployed on permissionless blockchains as stateful applications, represent both users and contracts through addresses that execute transactions to change the state. Transactions are broadcast to the network, sequenced into blocks, and circulated, triggering global state changes.

DAOs utilize smart contracts to create rules-based entities, with multiple interacting contracts handling treasury management, vote tallying, and token operations. These interactions are managed through transactions and state changes, with the protocol layer ensuring consensus and block distribution, the application layer hosting the smart contracts, and the user interface layer facilitating transaction creation and signing. DAO voting requires users to maintain governance tokens and sign transactions to indicate proposal preferences, using methods ranging from off-chain signature collection to direct vote tallying and code changes by the DAO contract. To address voter apathy, DAOs often implement vote delegation features, allowing token holders to assign their voting power to third parties without losing custody of their tokens, illustrated in paper 1 [47] with a demonstration of a layered taxonomy, inserted here again as figure 5.1 for context.

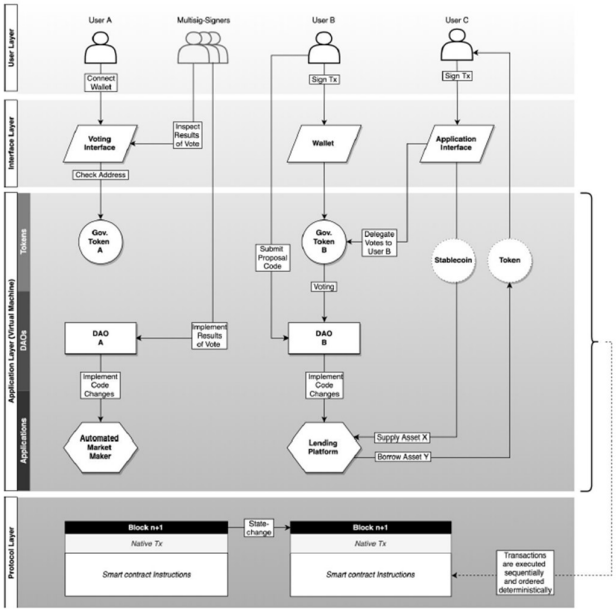

Figure 5.1. DAO taxonomy. From paper 1 [47].

In paper 5 [38] we conducted a comprehensive analysis of DAO definitions and how they have evolved over time, identifying nine key themes: (i) Decentralization and distribution; (ii) Autonomy and automation; (iii) Organization and operations; (iv) Smart contracts and permissionless blockchains; (v) Self-governance and code-based governance; (vi) Token economy and incentives; (vii) Human involvement; (viii) The legal and formal structure; and (ix) The scope and potential.

The concept of DAOs was first introduced by [130], long before the emergence of popular blockchains such as Ethereum, which hosts the bulk of DAOs today. Dilger introduced the concept of a decentralized autonomous organization as a framework for describing and designing a complex, multi-agent 'intelligent' home system. This system would self-organize through an evolutionary process and sustain itself using immune system principles rather than functioning as an organization in the traditional sense.

Table 5.1 lists the definitions/references extracted from a literature review that formed the input to paper 5 [38]:

Vitalik Buterin 2014 [131]	"It is an entity that lives on the internet and exists autonomously, but also heavily relies on hiring individuals to perform certain tasks that the automaton itself cannot do."
Wright and De Filippi 2015 [132]	"These organizations can re-implement certain aspects of traditional corporate governance using software, enabling parties to obtain the benefits of formal corporate structures while at the same time maintaining the flexibility and scale of informal online groups. These organizations can also operate autonomously without any human involvement. They can own, exchange, or trade resources and interact with other humans or machines, raising novel questions around traditional notions of legal personality, individual agency, and responsibility."
Jentsch 2016 [133]	"A method that for the first time allows the creation of organizations in which (1) participants maintain direct real-time control of contributed funds and (2) governance rules are formalized, automated, and enforced using the software. Specifically, standard smart contract code has been written that can be used to form a Decentralized Autonomous Organization (DAO) on the Ethereum blockchain."
Atzori 2017	"In a hypothetical, fully decentralized society run through smart contracts,

[134]	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 the distribution of resources, run reputation-based systems, or organize any services through crowdfunding."
Voshmgir 2017 [135]	"DAOs are the most complex form of a smart contract on a blockchain, where its governance is embedded into the code of the smart contract using complex token governance rules. […] DAOs are moving up the technology stack, thereby becoming fully virtualized through software, code executed on top of an increasingly opaque stack of distributed networking, and consensus technology such as the Ethereum blockchain or similar."
Chohan 2017 [136]	"A DAO is an organization that is run through rules encoded as computer programs called "smart contracts."
Davidson et al. 2018 [137]	"A DAO is a self-governing organization with the coordination properties of a market, the governance properties of a commons and the constitutional, legal and monetary properties of a nation state. It is an organization, but it is not hierarchical. It has the coordination properties of a market through the token systems that coordinate distributed action, but it is not a market because the predominant activity is production, not exchange."
De Filippi and Wright 2018 [138]	"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."
Hsieh et al. 2018 [139]	"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)."
DuPont 2019 [140]	"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."
Berg et al. 2019 [55]	"Distributed autonomous organizations are organizations built around smart contracts and a blockchain controlled in a decentralized manner by its owners."
Singh and Kim 2019 [27]	"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 [141]	"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 [142]	"The result is the emergence of new organizational designs, including that of a Decentralized Autonomous Organization (DAO), which uses the blockchain and smart contracts to establish governance without management or employees, run completely by computer code."
Vergne 2020 [123]	"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."
El Faqir et al. 2020 [30]	"DAOs are organizations where the interaction of members (humans or machines) is mediated by a blockchain application, which is controlled by a set of rules embedded in its source code."
Hassan and De Filippi [143]	"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)."
Faqir-Rhazoni, et al. 2021 [144]	"Pieces of software deployed on a blockchain which mediate the interaction of groups of people."
Wright 2021 [42]	"The boundaries of what qualifies as a DAO are still evolving, but in their current form, DAOs rely on blockchains, autonomous smart contracts, and digital assets to support organizations that operate natively on the Internet and have the capability of scaling globally from their birth."
Rozas et al. 2021 [57]	"A DAO is a blockchain-based system that enables people to coordinate and self-govern themselves mediated by a set of self-executing rules deployed on a public blockchain, and whose governance is decentralized."
Mini et al. 2021 [145]	"A decentralized autonomous organization (DAO) is a distinct form of platform meta-organization that heavily relies on smart contracts running on blockchains to govern a distributed network of autonomous actors, thereby continuing the shift toward governance via IT."
Ziegler et al. 2022 [146]	"Decentralized Autonomous Organizations (DAOs) are trustless organizations that automate transactions, operations, and decisions without a trusted third party."
Bellavitis et al. 2022 [147]	"Decentralized autonomous organizations (DAOs) are blockchain-native, decentralized organizations that are collectively owned and managed by their members via smart contracts."
Zargham and Nabben 2022 [148]	"Decentralized autonomous organizations (or DAOs) are a manner of self-organizing among multiple stakeholders towards a stated objective, via digital tools."
Overhage and Widjaja 2022 [149]	"Decentralized autonomous organizations (DAOs) are blockchain-based organizations that manage resources through self-executing rules defined in smart contracts and rely on decentralized governance approaches."
Wiriyachaokit et al. 2022 [150]	"DAOs can be viewed as a form of meta-organization, which comprises autonomous actors who are not legally bound by traditional authority."
Santana and Albareda 2022 [45]	"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 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.

Pahuja and Taani 2022 [151]	"Decentralized Autonomous Organizations are virtual communities in the blockchain ecosystem that are managed by smart contracts, owned by the members, and lack central leadership."
Rikken et al. 2023 [152]	"A DAO is a system in which storage and transaction of value and notary (voting) functions can be designed, organized, recorded, and archived, and where data and actions are recorded and autonomously executed in a decentralized way."
Qin et al. 2023 [44]	Define DAOs from a broader and more precise systems and operations angle as organizations and operations that "summarize key principles as distributed and decentralized (D), autonomous and automated (A), and organizational and operational (O)", where, "A true DAO should meet different requirements for D and A, e.g., the organizational form and allocation of rights and responsibilities from the perspective of organization, and the decision-making and implementation methods from the perspective of operation", all depending on i) their basic principles and setting requirements for each, ii) infrastructure setting - "DAOs can be regarded as multiagent systems with social and engineering complexity", and iii) supporting technology, where "the advanced [future] form refers to that DAOs can serve specific organizations with multiple goals and complex functions, with robots and digital humans assisting humans; the ideal form means DAOs can be used for society with ecological goals and functions, with robots and digital humans guiding humans" including with a view to both digital twins and metaverses.
Lu et al. 2023 [153]	"A novel form of digital organisation that is community driven and reliant on group consensus. At its core lies a revolutionary idea that organisations can function without a central authority calling the shots."
Augustin et al. 2023 [154]	"Understanding decentralized autonomous organizations from the inside'. "DAOs are characterized by globally distributed members with a shared purpose that use blockchain technology to virtually collaborate in a non-hierarchical, decentralized fashion with the help of a digital token."

Table 5.1. Definitions of DAOs.

5.1 The evolution of DAOs

Figure 5.2 outlines how DAO definitions evolve from early theoretical constructs to entities with practical applications and legal standing.

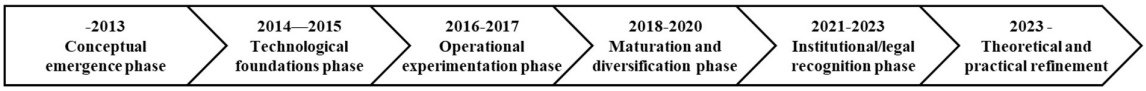

Figure 5.2. Timeline – evolutionary innovation phases in DAOs.

A conceptual phase emerged in 2013, with the early conceptualization of DAOs tied closely to the nascent blockchain technology, focusing on decentralization and autonomy as theoretical ideals. The innovation in this early phase was the introduction of the term DAO and its association with blockchain, emphasizing decentralization and the potential for autonomous operations. The conceptual phase matured into a technological foundations phase in 2014-2015, where the emergence of Ethereum and smart contracts provided a tangible technological foundation for DAOs. The innovation in this phase was using smart contracts for governance and operations, showcasing the practical application of DAOs beyond theoretical constructs.

In 2016, an operational experimentation phase replaced the foundation phase, during which high-profile DAO projects (e.g., 'The DAO') began demonstrating their potential and pitfalls, including security vulnerabilities. This phase's innovation was real-world experimentation, and the first major implementations led to increased awareness of DAOs' potential and challenges.

A maturation and diversification phase emerged in 2018-2020, where diversification of DAO applications beyond finance included arts, community governance, and more. Legal structures for DAOs began to be explored. The innovation focused on the expansion of DAO use cases and the exploration of legal frameworks for DAOs, indicating the maturation of the concept and its integration into various domains. This was superseded by an institutional integration and legal recognition phase in 2021-2023, with emerging legal recognition in certain jurisdictions (e.g., Wyoming's DAO LLC regulation) and increased interest from institutional entities. The innovation focus in that phase was on legal and regulatory advancements to solidify DAOs' place in the broader organizational and legal landscape, enabling more secure and recognized operations and looking to establish a solid foundation of agency with limited liability for members established through incorporation. The concept of 'legal wrappers' emerged [155] as a concept to shield liability for DAO community members, removing the risk of personal liability if the venture would be classified as a general partnership, as discussed in paper 2 [48]. The liability challenge aside, such 'legal wrapping' clearly constitutes agency, which contradicts the notion of something being decentralized in the context of DeFi.

Without sufficient data, it is difficult to describe the present in evolutionary terms. Yet, with the increasing focus on DAOs' theoretical and practical 'fit' also in a regulatory context, the present might be described as a theoretical and practical refinement phase as DAOs continue to increase and find solid use cases, evolving toward more sophisticated governance models, integration with emerging technologies, and exploration of ethical implications.

Scholars agree that DAOs relate to permissionless public blockchains, and in the same paper 5 [38]To capture this evolution, we proposed a forward-looking definition of DAOs. This definition underscores the impact of blockchain innovations, smart contracts, evolving legal frameworks, and emerging technological innovations on DAO development.

"A DAO is a collaborative, open, blockchain-enabled platform governed by smart contracts designed to operate without centralized control. A DAO orchestrates interactions, asset management, and decision-making through coded rules to achieve common objectives, with global reach and integration with digital and virtual environments."

Backtracking this definition to the nine themes identified in the thematic analysis we undertook in paper 5 [38], a few themes are deliberately left out: (i) token economy and incentives, (ii) human involvement, (iii) legal and formal structure, and (iv) scope and potential. The proposed new contemporary definition captures those in the following manner: (i) Although there is no mention of tokens or incentives that drive participation and alignment of interests within the DAO, we implicitly incorporate this topic under 'orchestration' and 'interactions.' (ii) While the definition emphasizes automation and coded rules, it does not highlight the role of human participants in proposing and voting on changes except through the word 'interaction.' This is on purpose as we are not certain of the extent of the human element required as part of decentralized decision-making; on the one hand, it creates an attack vector; on the other hand, it is clear that humans form part of organizations. However, recognizing the potential influence of AI acting as autonomous agents as we move forward, we opted not to include this theme specifically. (iii) The definition does not address how DAOs consider or fit within legal and formal regulatory frameworks. This is also deliberate as legal structure suggests agency and a truly decentralized entity does not have agency on its own; it evolves around 'participation without legal boundary' [42]. Scope and potential have been captured in 'global reach and integration with digital and virtual environments.'

5.3 Properties of blockchain in the context of DAO characteristics

From the contemporary definition presented above, a DAO must fulfill its unique and specific decentralization and autonomy criteria within its organizational and operational frameworks to deliver its objectives. This means that organizationally, DAOs should have no central or subordinate nodes; they should allow open, voluntary participation and utilize fair, consensus-driven decision-making and rights distribution. Operationally, DAO decisions should be automated using smart contracts, ensuring its autonomy is sustained with a coordination cost that is relatively attractive to centralized authority, limiting single-node influence while also being tamper-proof. Such a structure supports a

robust, self-sustaining system that resists central control and promotes equitable member involvement for long-term survivability.

Where scholars [123][45][44] generally agree that the nuances of the 'D,' 'A,' and 'O in DAOs in the context of the 'D' refer to decentralized, but also distributed, the 'A' to autonomy, but also automation and the 'O' to an organization, but also to its operations. However, we notice specific nuances to these in the context of DAOs operating in regulated finance.

5.3.1 Distributed vs Decentralized

As pointed out by Vergne [123] decentralization and distribution in an organizational context are not simple questions of power. It becomes complex, as processing information and making decisions around the same issue does not necessarily occur as part of the same movement nor necessarily performed by the same agents. This is in line with recent regulatory interpretations, where, as regards financial services, regulators differentiate between technical and organizational decentralization and also require services offered in a decentralized manner or controlled by legal personality [156]. As mentioned before, there is no agency if a service is fully decentralized.

Assessing the 'concentrated-distributed' vector empirically could be done in several ways [45][140][156][157]: (i) Participation rates in decision-making, where one measures and compares the participation rate of members with high participation rates can indicate a more distributed decision-making process; (ii) Voting pattern analysis of blockchain data to analyze voting patterns within DAOs, such as the distribution of votes across proposals and the distribution of voting power among members; (iii) Decision-outcome analysis, where one could quantify the number of decisions made over a period and their outcomes, with a greater variety of decision outcomes suggesting a more distributed decision-making process; (iv) qualitative analysis, including document analysis of DAO constitutions and community for a material, or via interviews and surveys with DAO members to understand their perceptions of the decision-making process to shed light on whether they feel decisions are made in a concentrated manner or are widely distributed.

The 'information-coordination' vector (Centralized vs. Decentralized) manifests itself either in a centralized manner, with centralized control of knowledge management and consultation processes, or in a decentralized fashion, supporting a more dispersed approach to handling information. Quantitative and qualitative methods can be applied to assess this vector pragmatically, including network analysis to evaluate communication patterns and assess information flow speed and reach, looking for signs of decentralized coordination, where a more decentralized information system might show a distributed network in which information flows freely among participants without central bottlenecks and faster/broader dissemination could indicate decentralized coordination.

Centralization can be observed in many aspects of a DAO's 'TIGER' dimensions that we designed in paper 1 [47]: (i) Token-weighted voting and incentives – if a small group of individuals or entities holds a majority of the tokens that grant voting power within the DAO, they can effectively control decisions. (ii) Infrastructure, where developers who create and maintain the DAO's smart contracts may significantly influence its operation. Suppose the community heavily relies on a small team of developers. In that case, these developers can have centralized control over code updates and changes through their cryptographic keys, for example, if they are held by a small, closely-knit group vs. a diverse group of verified independent agents with no collusion or close affiliations. (iii) Governance, where the governance structure of the DAO might inherently favor centralization. For example, if the voting mechanism or proposal system prioritizes certain members or stakeholders, it can centralize decision-making power. (iv) Escalation, where mechanisms for handling crises, resolving disputes, voting access, or inflation calculation may lead to centralization. (v) Reputation, where external pressures or influence from large investors, partnerships, or other external entities can centralize control. Infrastructure elements such as hosting user interfaces, controlling off-chain oracles, and managing development repositories can be increasingly centralized. If a single entity or a small group controls these critical points, they can exert significant control over the DAO.

In terms of DAO suitability in finance, the recent regulatory and judicial developments suggest that a DAO may be suitable for regulated financial services if it is not only technically and organizationally

decentralized (paper 1 [47]), but also only if the service offering is delivered decentralized. There are several key limitations to this, a few of which are fundamental (paper 3 [49]):

1. Finality and probabilistic consensus: The use of DLT and blockchain in financial market infrastructure (FMI) requires finality to reduce settlement risk [159]: "An FMI's rules and procedures should clearly define the point at which settlement is final. An FMI should complete final settlement no later than the end of the value date, preferably intraday or in real time, to reduce settlement risk." Settlement finality principles ensure that financial transactions are completed reliably and securely. First, once a transaction is settled, it should be final and irreversible, meaning parties can confidently rely on the outcome. Second, the rules for finalizing a transaction should be clear and predictable so participants understand when and how settlement finality is achieved. Lastly, the system should be robust enough to handle a participant's default without impacting other transactions, ensuring stability even in adverse conditions. The settlement finality requirement is relevant for DAO's suitability in financial services as they typically operate on permissionless blockchains that use probabilistic consensus. This means that forks may exist for days or weeks before the final fork is determined. Generally, this makes such blockchains unsuitable for financial market infrastructure for financial stability reasons; considering the daily volumes in regulated financial markets, it would be practically impossible to roll back several weeks of clearing. Similarly, DAOs operating on such blockchains would not be suitable for financial infrastructure.
2. Cash settlement of securities and the DLT pilot regime regulation. Current EU regulation requires securities to be settled in commercial or central bank cash. As stated earlier by the BIS' visions of the Finternet, the benefits of DLT and blockchain cannot be achieved so long as there is no central bank digital currency. This makes it potentially difficult for a DAO to compete in securities markets, as stablecoins are not cash representatives in the context of securities settlement.
3. Lack of agency means enforcement is difficult to impossible. As discussed in paper 2 [48] and earlier, the OFAC sanctions against blockchain wallets associated with Tornado Cash are real. MICA, the EU markets in crypto assets regulation coming into effect in 2024, hold similar provisions, enabling regulators to close crypto asset service provisions if they find that a decentralized actor violates the rulebook, decentralized or not. Whether such an action is within the authorities' control is a question for the courts to confirm.

5.3.2 Autonomy vs Automation vs Adaptiveness

Autonomy in DAO implies that the organization will persist, and community-approved decisions will be executed autonomously on-chain forever, irrespective of the DAO's membership makeup. Such a setup is challenging for projects with a 4/7 multi-signature wallet (multi-sig) using Snapshot to poll and call themselves DAOs. Grey literature frequently asks 'how such organizations can persist autonomously when much organizational matter happens off-chain, and decision execution in this instance depends upon only a small group of trusted humans' [160]. The notion holds some truth, as DAOs can be considered 'organizational design patterns for building and upgrading autonomous, blockchain-based organizations composed of people and code.' Their smart contracts may execute autonomously but are not autonomous because they are automated.

First, a smart contract relies on external function calls initiated through human input [141]. Second, DAOs use democratic voting processes and token incentives based on transparency and individual value distribution instead of bureaucratic, opaque, centralized systems. Hence, the 'A' (Autonomous) relates mainly to censorship-resistance, self-sovereignty, and independence in human-machine interactions, not automation. This enables community autonomy with the goals of co-ownership, co-governance, and co-construction to realize [45].

As DAOs also rely on some level of automated governance through smart contracts, some scholars include automation in the 'A' dimension [35][42]. This is perhaps a bit confusing when 'A' relates to censorship resistance. Nevertheless, it is meaningful to include automation in the context of DAOs as they are digital native organizations, living on a blockchain and using smart contracts for their

decision-making, suggesting a high level of automation to be expected by design, also to suppress agency cost [56].

This automation perspective is further exacerbated by the emergence of artificial intelligence (AI). In paper 6 [52], we investigated the potential for using generative AI as an internal control mechanism for off-chain community moderation and cultural preservation, where we found it quite promising, with the potential to reduce the cost of coordination (agency cost) by 95 pct. The question is whether such an 'autonomous AI agency' falls into the autonomous nature of DAOs overall or the automated nature of DAOs, or it is a third 'A' feature – 'adaptiveness,' as briefly discussed in the introduction, driving yet another level of evolution into the DAO space.

Digital platforms demonstrate 'data network effects' when a platform's value to each user increases as it learns more from the data gathered about its users [161]. As digital-first organizations, DAOs are receptive to exploring such effects from the automation and AI perspective. While machine learning (ML) (and other AI, including foundation models) can increase human cognitive capacity, thereby increasing organizational leverage and reducing agency cost, some AI models, like foundation models, are extremely centralized.

Centralization contradicts the whole ethos of blockchain, as blockchains decentralize data and make it redundant with a replication algorithm, thereby reducing the need for continuous consultation. As blockchain transaction data increases, this inherent characteristic may lead to bottlenecks and latency, blockchain's so-called scalability problem [162], which might drive efficiency efforts in the opposite direction, frequently requiring side chains for non-essential information. That is unless technological advancements solve this through decentralized AI [163], a separate topic outside the scope of this dissertation. Therefore, ML/AI and blockchain may impact the structural dynamics of digital platform operators differently, influencing the relative efficiency and effectiveness of centralized versus decentralized decision-making and centralized versus distributed communication methods.

A key question is, therefore, what level of (off-chain) automation for DAOs is meaningful or desirable to pursue. At a minimum, aligning AI automation with the decentralized principles of DAO should be restricted to use cases where AI is used to bolster efficiency and maintain decentralization, not to centralize power or decision-making.

Use cases that come to mind within the current state of AI are (1) automated data analysis and reporting to enhance decision-making with AI-generated insights, for example, in community moderation and contribution or support FAQs; (2) smart contract enhancement, using AI to improve contract adaptability; (3) decentralized governance tools, where AI aids in managing governance processes; (4) predictive analytics for risk assessment, providing foresight into potential outcomes and risks; (5) fraud detection and security, leveraging AI for enhanced security measures; (6) tokenomics, the economic aspects of a cryptocurrency or blockchain project based on the design and distribution of its native tokens and the economic modeling thereof, using AI for financial decision-making and economic simulations; and finally in implementation of (7) decentralized AI through edge or federated learning [164], which aligns with the DAO decentralized ethos.

The autonomy vector in DAOs highlights how the tasks and processes within an organization are executed without human intervention. While traditional organizations may incorporate automated processes to a certain extent, DAOs push this further by embedding autonomy in their core operations through smart contracts that automatically execute actions based on predefined rules, as discussed earlier.

Some scholars [165] propose that a DAO's autonomy is defined by its ability to legally accept liability. From that perspective, a DAO's autonomy level can be assessed financially by the total liability it can absorb. This starkly contrasts the current legal enforcement actions and decentralization perspectives presented earlier, where a DAO has agency unless it is fully decentralized, both from a technology and organizational perspective, and its (financial) service offering is also fully decentralized.

If autonomy is defined as the ability to accept liability, then a Decentralized Autonomous Organization is impossible, as is an ant colony that operates autonomously in nature. Either a DAO has agency or it does not. Rather, decentralization and autonomy coexist in DAOs as complementary concepts through decentralized decision-making structures that empower smart contracts to execute actions autonomously. Both concepts are critical, with decentralization enabling a more democratic decision-making process and autonomy ensuring that decisions are tamper-proof. Balancing the two involves designing decentralized governance structures that allow smart contracts to function autonomously.

The degree of autonomy can be evaluated by analyzing the extent to which processes are managed by smart contracts, including automated decisions that are made without human curation. For example, smart contracts or AI in decision-making could be quantitatively assessed and compared to other types of decision-making to understand the extent of autonomy. This would include reviewing the functions these contracts automate and the decision types they cover, from governance votes to financial transactions. Process flow mapping could be conducted in both DAOs and traditional organizations, mapping out key processes and identifying which steps are automated vs. those that require human intervention. A human intervention index could be potentially developed, quantifying the level of human intervention needed for the organization's decision-making and control processes. The index could consider the frequency, importance, and diversity of tasks needing manual inputs.

Unlike the autonomy vector, the automation vector in DAOs is facilitated by technology (e.g., smart contracts on a blockchain), and the default position would be that DAOs are more automated than other digital types of organizations. Automation underscores the efficiency and effectiveness of executing tasks without manual oversight. DAOs implement automation across all operations, from governance to financial transactions, but frequently with a level of human curation.

IS scholars have begun to discuss the AI-enabled DAO [166]; however, it is important to note that principal-agent liability does not hold accountable the numerous actors involved in computer use, such as programmers, manufacturers, and traders. Instead, it solely targets the user who delegates a task to the technology, thereby assuming the risk of the algorithm's autonomous decision-making. Thus, only the human user or operator (or organization) is liable for algorithmic failures [167], and recognizing the agency of algorithmic systems does not eliminate or transfer human accountability for the harms they cause [168].

While bots and assistants may drive productivity and enhance products and services from an automation perspective, AI may also become an integral part of the autonomy of DAOs, as token holders or community members interact with smart contracts, the latter through contribution policy. AI may also become a connector within or between DAOs, perhaps forming ‘swarm intelligence’ with DAOs governing AI as a public good to boost safety. AI ultimately becomes the DAO, owning a treasury on-chain in such an evolving landscape.

Eventually, smart contracts, with or without the integration of AI, may auto-dispense rewards to those who contribute to a precisely defined objective function. On reflection, this could lead to full decentralization and autonomy and the possibility of abandoning the DAO concept altogether [169], [170], but it could also, ironically, lead to centralization if a truly decentralized DAO is replaced by a more centralized multi-sig, which would control the smart contracts and AI.

5.3.3 Organization vs Operation

The operations vector focuses on the day-to-day activities and how they are conducted within the organization. As discussed above, DAOs leverage decentralized, distributed, and automated processes for their operations, which can differ greatly from the more manually driven and centralized operations in traditional settings. By comparing the operational efficiencies, response times to decisions, and the implementation of projects, the impact of DAOs' operational models can be assessed, for example, using key performance indicators (KPI) on transaction processing time, cost per transaction, or the number of processes automated. Notwithstanding deliberate delay mechanisms as part of democratic voting, such as conviction voting [32], KPIs can help assess how decentralized

decision-making impacts operational speed, and process mapping can identify bottlenecks, decision points, and automation potential, perhaps even using machine learning to detect anomalies and compare the maps to identify operational differences and efficiencies within similar processes in DAOs vs other digital forms.

The organization's vector pertains to the overall structural and governance models of DAOs compared to traditional forms. It encompasses how DAOs are pioneering new ways of organizing collective action and resources beyond the conventional corporation or cooperative models. Analyzing the legal structures, governance frameworks, and participatory models of DAOs in contrast with those of traditional organizations provides insights into how organizational forms are evolving.

5.4 Research contributions

To categorize the research contributions to this taxonomy, we label each of the papers included in this dissertation to the dimensions of this D-D-A-A-A-O-O taxonomy:

1. 'When is a DAO decentralized?' (Paper 1 [47]) investigates organizational and governance models of DAOs in a regulatory context and how blockchain technology challenges conventional organizational structures and governance models. Through developing an assessment framework for DAO decentralization, this paper covers decentralization, distribution, autonomy, automation, operations, and organization.
2. 'How should DAOs be regulated?' (Paper 2 [48]) navigates through the conceptual and operational intricacies of DAOs, assessing their operational models against regulatory landscapes and highlighting their transformative potential in challenging conventional governance. The paper also stresses the need for adaptive regulatory frameworks to accommodate these novel organizational structures without stifling innovation. The paper contributes insights into decentralization, autonomy, organization, and operations.
3. 'Trading Green Bonds using DLT' (Paper 3 [49]) creates a link between centralized capital market infrastructure with stringent criteria for finality and settlement and permissionless blockchains in DeFi that often use probabilistic consensus models. The multi-sharded distributed technology platform design with deterministic consensus to bridge traditional capital market regulatory requirements to carbon credits deployed on any ledger, including permissionless, public blockchain with probabilistic consensus mechanisms that lack the regulatory expectation of real-time finality, the paper contributes perspectives into distributed vs decentralized operations and systems automation.
4. 'DLT for compliance reporting' (Paper 4 [51]) investigates the applications of DLT for compliance reporting in the financial sector, spotlighting how the technology can streamline regulatory processes and enhance operational efficiency. The paper contributes insights mainly into automated operations using distributed systems.
5. 'Do you need a DAO?' (Paper 5 [38]), adopts a critical lens towards the DAO phenomenon, posing the fundamental question of their appropriateness in various organizational contexts. This work diverges from the broader theme of championing decentralized technologies, offering instead a nuanced perspective on when and why a DAO might (not) be the optimal solution for governance or operational needs. The analysis paves the way for further research that interrogates the conditions and contexts conducive to the effective use of DAOs, which we elaborate on below. The paper contributes insights across the spectrum of decentralization, distribution, autonomy, automation, operations, and organization.
6. 'Scaling Cultural Production in Blockchain-based Gaming' (Paper 6 [52]) deploys generative AI within semi-decentralized ecosystems and presents an innovative approach to managing community dynamics and fostering a shared sense of identity and purpose. As the field of generative AI has exploded since the introduction of OpenAI's ChatGPT to the public in late 2022, the methods applied in the paper are quickly becoming mainstream in DAOs to harness cultural economics, organizational resilience, and learning. Yet, the technology synergy and combining blockchain and generative AI to manage member contribution is still immature in DAOs (and more traditional forms of organization), not least because of privacy and ethics concerns. The CityDAO case inspired the research [171]. CityDAO suffered a major setback

due to inadequate internal procedures and controls to manage hypergrowth. Here, it is presented as a case of maintaining identity amidst rapid growth and the unique pressures these communities face, including pseudonymity and equitable value distribution, and proposes AI-driven solutions for cultural preservation and community management. The study serves as a microcosm, reflecting broader socio-economic considerations necessitated by technological growth, and the paper mainly contributes to automation, adaptiveness, autonomy, operations, and organization.

Figure 5.3 outlines how the papers contribute to the taxonomy, using a 6-circle Venn diagram with the third 'A' (adaptiveness) potentially affecting all dimensions.

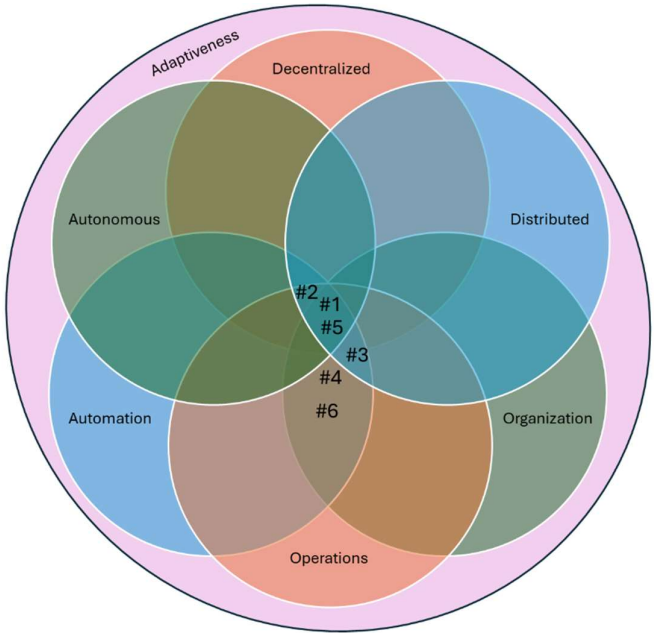

Figure 5.3. Mapping research papers to a DD-AAA-OO taxonomy.

6. A framework for fitting DAOs to regulated finance

This chapter derives evaluation items for an assessment framework to determine whether a DAO is an organizational fit for financial services, consolidated in Table 6.2 further below. The items are derived from the research papers' work supplemented with relevant academic literature required to build a comprehensive framework for assessing DAO suitability in regulated finance, aiming to systematically connect across the papers of the dissertation, using the method for the integrative chapter discussed in the methods chapter.

First, we complement Daft's organizational design theory discussed in the background chapter [115] as regards DAOs [37] and contribute additional key design elements. Then, we consolidate the dimensions from paper 5 [38] with the additional insights derived from the theoretical framing chapter and the other research papers in the context of regulated financial services. Then, we generalize and cluster the dimensions into four meta-themes and evaluate the framework on three prominent DeFi protocols.

6.1 Theoretical framing of DAOs to organizational design theory

By reducing transaction costs, conforming to institutional norms, and fostering collaborative peer production, DAOs provide a novel organizational form that challenges traditional structures. From a transaction cost perspective, DAOs achieve specialization through smart contracts and token-based governance. This specialization minimizes bounded rationality by automating decision-making and reducing opportunistic behavior through transparent protocols. From an institutional perspective,

DAOs establish formal governance structures encoded in smart contracts. This formalization aligns with institutional norms, allowing DAOs to gain legitimacy while adhering to their decentralized ethos. Their token-based incentive systems foster collaboration, while decentralized governance enables peer production and decision-making.

Economic scholars [56] suggest that the viability of DAOs as an organizational form depends on the cost of smart contract operations suppressing agency costs. While this notion is sensible from a transaction cost perspective, there may be other benefits to measuring organizational effectiveness than agency cost from, for example, a Commons-Based Peer Production (CBPP) community perspective [55][56]. CBPP is a model of socioeconomic production where groups of individuals collaborate to create shared resources without relying on a traditional hierarchical structure [172]. CBPP communities are characterized by Ostrom's principles for public good, or commons, governance [59]. Ostrom, the 2009 Nobel laureate in economics, studied the governance of common pool resources and developed principles for their successful management and how to avoid 'the tragedy of the commons' such as freeriding. The difference between the traditional view of 'firms' and 'commons' lies between 'community governance,' which involves collective decision-making and sustainable resource management, and 'private governance,' which focuses on corporate or private interests and profit. Ostrom's eight principles for the governance of a public good are "(i) Clearly defined boundaries, (ii) Congruence between rules and local conditions, (iii) Collective-choice arrangements, (iv) Monitoring, (v) Graduated sanctions, (vi) Conflict-resolution mechanisms, (vii) Minimal recognition of rights to organize, and (viii) Nested enterprises" [59]. As a digital 'commons' adapting, Ostrom's eight principles would aim to harmonize stakeholder participation with operational efficiency but introduce relationship dimensions as equally or more important than transactional costs, yet still within the theoretical concept of an 'organization.'

DAOs represent a further evolution within digital organizations, embodying socio-technical ecosystems that blur traditional distinctions between systems and organizations. DAOs aim for a paradigm of decentralization and autonomy by ingraining organizational processes within blockchain technology. These ambitions are often tempered by practical inhibitors, including legal issues and the centralization of decision-making powers, but from a design perspective, DAOs are unique in several dimensions not fully captured by [115], as also discussed in paper 5 [38]:

- Decentralization of authority: Unlike traditional organizational structures where authority and decision-making power are centralized within a hierarchy, DAOs distribute authority across all members. This decentralization is enabled by blockchain technology, allowing for transparent and secure collective decision-making without a centralized point of control.
- Consensus-based decision-making: DAOs rely on consensus mechanisms for decision-making, wherein changes to the organization, its governance, or protocols can only happen if there is majority agreement among members. This is very different from the managerial decision-making processes found in conventional organizations.
- Incentive structures: DAOs often use tokens as a medium of exchange within the organization to incentivize and reward contributions. Tokenomics – the economics of these tokens – defines how they are distributed, earned, and used within the DAO, which introduces a novel economic dimension to organizational design as also highlighted in the introduction chapter.
- Smart contract governance: DAOs are governed by smart contracts, self-executing agreements with the terms directly encoded into lines of code. This enables the automation of organizational governance and rule enforcement without the need for intermediaries, differing from legal contracts and human governance in traditional organizations. This differentiation of DAOs contrasts significantly with traditional organizations regulated by laws and legal agreements enforced by a country's legal system. Instead, as entities native to permissionless blockchains, DAOs are governed by agreed-upon rules embedded in an open-source protocol or a smart contract, which can only be modified through a majority rule agreed upon by its members.
- Fluid membership and roles: Membership and roles within DAOs can be more fluid than in traditional organizations, where positions are often fixed and hierarchically structured. In

DAOs, individuals can freely join or leave, and their roles can evolve based on their contributions and engagement levels, facilitated by blockchain technology.

- Transparent operations and records: All transactions and decision-making processes within a DAO are recorded on their native blockchain, ensuring high levels of transparency for on-chain decisions. Off-chain decisions such as proposals are also frequently accessible. This is a departure from the informational silos and opacity that can exist within conventional organizations.
- Integration of technological and organizational design: In DAOs, technology is not just a tool for facilitating operations but is deeply integrated into the very fabric of the organizational structure and governance. This symbiosis of technology and organizational design challenges traditional separations between IT infrastructure and managerial processes.
- Global and borderless operation: DAOs operate globally without being bound by geographical borders or jurisdictions. This global reach and operational flexibility challenge traditional concepts of organizational locational strategy and international business operations. They also challenge DAOs focusing on regulated activities, such as finance, where DAOs proliferate within decentralized finance (DeFi).

DAOs' initiation and operational dynamics go beyond technical underpinnings, engaging with broader socio-economic and institutional theories [45]. Collaborative-form organizations (so-called C-form) show a positive correlation between formalization and decentralization, mirroring DAOs to some degree [37]. In Daft's theoretical framework, an organic design usually features a decentralized structure. This type of design is often associated with smaller organizations, a strategy that prioritizes learning and innovation, a dynamic environment, service-oriented technology, and an adaptive culture. However, since DAOs require a minimum size for viability [152], formalizing DAOs as organizations – or considering them as automated operations or centralized C-form organizations – impacts the outcome. This impact is at least as substantial as, if not greater than, the effects of some of Daft's other organizational design dimensions.

Given their uniqueness and the data discussed earlier, that DAOs primary application is in finance, the question of decentralization becomes critical and unique for their long-term survivability, as discussed in the background chapter and papers 1 [47] and 2 [48]. This informs the design of DAOs' organizational structure in terms of the level of professionalism required to undertake daily operations, its empowered roles, informal systems, horizontal communications, and collaborative teamwork. This leads to two 'DAO modifications' that are critical to fit DAOs further into Daft's organizational design theory [115], centering around the mission and what the community aspires to achieve with their DAO.

6.1.1 Implications of Regulation

First, the regulatory implications of a DAO's level of decentralization become significant from an organizational design perspective, perhaps more important than the other ten organizational design dimensions presented by Daft.

Further, just because you decentralize does not mean risk disappears. This means that DAOs offering financial services (or other highly regulated service offerings) should have a higher level of (risk and compliance) professionalism and formalized structure for long-term survivability, even if they can operate without formal compliance, as there is no agency to hold accountable.

This is significant from a design perspective, and accordingly, we propose an extension to Daft's theoretical framework [115] with regulatory compliance as an 11th 'DAO design' dimension.

#	Dimension	Description of DAO in the context of Daft dimension
11	Regulatory compliance	Depending on the regulatory treatment and the true level of decentralization, either high or low professionalism and capital requirement

6.1.2 Implications of Business Objective Function

Second, we hypothesized in paper 5 [38] that DAOs fit best with medium-wide objectives.

DAOs may leverage tokenomics to reduce asset specificity by enabling trustless exchanges through smart contracts. This flexibility in managing digital assets aligns with a wide range of business objectives, and they can effectively manage digital commons.

Their open-access nature and decentralized governance also make them ideal for collaborative production in emerging digital economies. Yet, they are potentially superfluous for narrow objective functions, as any organizational bureaucracy is a potential centralized attack vector, as suggested by [169] in line with the 'governance minimization' principle introduced by [173], which posits that automating open-source software components represents a robust form of decentralization

By a narrow objective, we mean a specific function, limited in scope, that can be automated through smart contracts with minimal decision-making complexity and without requiring a governance mechanism beyond a smart contract. This could be token distribution protocols, where smart contracts automatically distribute tokens to holders based on predefined rules (e.g., dividend distribution), or it could be Automated Market Makers (AMM) [99], where liquidity pools automatically match buyers and sellers, as discussed in the evaluation below. It could also be any escrow service that holds assets until predefined conditions are met.

The 'fit' would match any business model requiring concentrated decision-making distribution, centralized or decentralized information coordination, high automation potential, and minimal compliance.

DAOs are potentially economically unfit from a transaction cost perspective for broader business objective functions that require high specialization or considerable human agency and curation [56]. DAOs may be able to manage broad, complex objectives that require considerable coordination and decision-making across diverse activities and stakeholders across multiple domains or activities. Still, at some stage, the cost of coordination and management of smart contracts becomes uncompetitive compared to agency costs in traditional organizations.

Examples of wide objective functions in DeFi could be DeFi ecosystem management, such as DAOs overseeing multiple DeFi protocols, governance structures, and community engagement. It could also be metaverse development, requiring management of a digital world with varied economic, social, and cultural activities (e.g., Decentraland DAO). These examples require distributed decision-making, decentralized information coordination, and high autonomy, and they necessitate a DAO structure due to their complexity and the need for decentralized governance. However, their long-term survivability may be questionable if agency cost is not managed and the DAO's product is a regulated (financial) service, where the (agency) cost of compliance is not negligible.

A prominent example is MakerDAO, a complex lending market using collateralized debt positions to fund a stablecoin soft pegged to the USD, the Dai. Due to complexity and high cost levels, the founder of MakerDAO introduced the 'Endgame' plan in May 2022 [174]. The plan was presented to the community "to deal with the major contradictions and challenges that I see, and also to ensure that the project gets on a path towards a truly decentralized equilibrium" through "a fully-fledged, economically sustainable DAO with significant synergy with Maker." This new DAO structure, a metaDAO, was presented as a silver bullet to the community to solve the problems experienced in the DAO so far with low levels of innovation and high costs. Introducing sub-DAOs should help manage the complexities of the protocol and keep agency costs in control.

The transformation was achieved through the centralization of protocol governance when the founder reclaimed his previously delegated governance tokens [157]. It is yet to be proven whether the subDAO structure is more manageable, profitable, and less complex. However, the proposal process and approval appear to be a strategic power move by the founder, resembling traditional organizational challenges related to the span of control and transaction costs. The example suggests that a DAO with such a broad objective function is unsustainable.

The middle-ground objective function balances narrow and wide, requiring some degree of human interaction and decentralized decision-making. The objective may involve some diversity of activities and require human decision-making at a moderate level. The decision-making complexity necessitates some decentralized governance. This could be the potential sweet spot for DAOs, and the dimension defines DAO suitability from a design perspective distinctly different from other types of organizations. Hence, we propose adding this additional dimension as a 12th dimension for organizational design unique to DAOs.

#	Dimension	Description of DAO in the context of Daft dimension
12	Objective function	Depending on the scope of the objective function, DAO may be more or less suitable from a design perspective.

Table 6.1 below maps the scope of an objective function (narrow-medium-wide) for typical financial services offered by DeFi protocols/DAOs. If the scope of DAO services requires a very narrow objective function, there is no need for a DAO as the objective can be fully automated. Conversely, if too wide, it is not viable from a transaction cost and decision-making perspective [56].

DeFi application	**Objective function**
On-chain asset exchanges	On-chain asset exchanges (including DEXs) aim to facilitate asset trading with varying complexity (AMM vs. order book DEXs). Their core goal remains relatively specific – to enable secure, decentralized trading. Hence, their objective function ranges from medium (order book DEX) to narrow (AMM).
Loanable funds markets for on-chain assets.	Loanable funds markets for on-chain assets (DeFi lending protocols) handle loans, staking, and yield farming. They involve risk assessments, collateral management, and sometimes complex liquidity algorithms. The range of activities makes the objective function medium to wide, depending on the specific scope of instruments.
Stablecoins	Non-custodial stablecoins (e-money tokens or asset reference tokens in MICA terms) aim to maintain stability against a peg, which can be complex given the need for managing reserves and responding to market dynamics. Although the focus on price stability is relatively singular, it can include complex control theoretical designs, and the objective function is, therefore, medium-wide.
Portfolio management	Portfolio management (including crypto or real-world asset management involves evaluating multiple assets, making investment decisions, and potentially adjusting strategies based on market conditions. This requires broad operations and adaptability, and the objective function is typically wide.
Derivatives	Derivatives (including synthetic assets, futures, perpetual swaps, and options) are complex financial instruments with varied underlying assets, leveraging, and hedging strategies. The objectives span risk management, speculation, and price discovery, and the objective function is, therefore, typically wide.
Mixers	Privacy-preserving mixers have a clear and specific primary goal: to enhance transaction privacy. Though technically challenging, the aim is straightforward and singular, so the objective function is typically narrow.
Insurance	Insurance (including decentralized insurance marketplaces) involves assessing risks, pricing policies, managing claims, and maintaining liquidity. While focused on risk mitigation, the breadth of operations needed is considerable, and the objective function is, therefore, medium-wide.
NFT marketplaces	Platforms for creating, buying, and selling non-fungible tokens (NFTs). As a marketplace, its objective function is narrow to medium, depending on how the exchange mechanism is defined.
Services	This is a broad category that includes governance, identity, oracle, or other infrastructure services that support DeFi and non-DeFi applications. The objective function can vary from narrow to wide.

Table 6.1. DeFi applications and typical objective function scope.

6.2 Assessment items for suitability assessment

With the design elements positioned for DAOs involved in financial services offerings, we now turn to the evaluation items informed by my work and the literature mentioned, finalizing the work we started in paper 5 [38] from the perspective of assessing DAO suitability in regulated financial services. For a balanced evaluation, we use a simple +/- score-based approach to the framework, similar to [175] and [31], but balanced, considering organizational design is not binary but ideally an optimization of conflicting objectives, where a '+' denotes a positive alignment to the suitability of using a DAO for DeFi services, and a '-' denotes the opposite.

1. **"Can the DAO operate in a potentially ambiguous legal environment without accountability?" (+)**

Consolidating papers 1 [47], 2 [48] and question number 2 in paper 5 [38], with the new DAO design objective 11, assessing the operational viability of a DAO in a legally and regulatory ambiguous environment requires attention to the evolving legal and regulatory uncertainties identified. It is vital to comprehend the legal frameworks affecting DAOs, such as the risk of members' liability and the significance of having legal identity and responsibilities. It is also important to acknowledge that in certain situations, stakeholders may demand centralized control when an activity provokes intense and widespread disapproval from the community, thereby necessitating prompt action by authorities, as illustrated in paper 2 [48] with the case of Tornado Cash. Such circumstances may arise when DAOs fail to adequately address stakeholders' reasonable expectations or violate regulatory standards or legal constraints affecting other similar organizations. The pseudonymous and permissionless nature of DAOs may also exacerbate this, leading to conflicts with industries or regions that require clear accountability and well-defined legal structures. This understanding should guide stakeholders in navigating legal complexities on blockchain platforms amid changing regulations.

Further, without formal incorporation, DAO members may face personal liabilities for their participatory actions, like voting, under the premise of an unincorporated partnership. This dimension can also be quantified within the D-D vector (decentralization) to assess how regulatory compliance impacts or is impacted by the level of decentralization in DAO operations. Despite their decentralized nature, DAOs must navigate complex regulatory landscapes. Institutional theory suggests that DAOs can achieve legitimacy by conforming to emerging regulatory frameworks while maintaining their decentralized governance structures. Yet, with regulators possibly requiring full decentralization across technical, organizational, and user interfaces for any regulated service offering, it may become excessively hard for a DeFi DAO to survive.

2. **Is the objective function and service offering scope suitable for a DAO? (+)**

As discussed earlier under organizational design objective 12 and as briefly touched upon in paper 5 [38], DAOs face challenges in coordinating wide objective functions that require expertise while being irrelevant for narrower objective functions where no organization is needed. Rather, the function can be coded directly into a smart contract, potentially supported by a human helpdesk or generative AI bots. In paper 3 [49] we discussed the throughput requirements for certain financial products. As captured earlier, permissionless blockchain is unsuitable for products requiring real-time finality or with extreme throughput requirements, given the limitations of block processing speed in such chains.

Without getting into details, another dimension here is whether a particular financial service is suitable for blockchain at all; for example, high-frequency trading or complex algorithms requiring high computing may be difficult to implement in block space, let alone permissionless block space. Other services, such as long-duration complex derivatives, might not be suitable for immutable blockchain processing if reliance on 3rd party interpretation/benchmark is required or recourse is needed for dispute resolution. The exact scope of the service offered determines the required level of professionalism in the DAO, which varies, being typically low overall but higher for the technical team. This reflects a flexible participation structure with higher requirements for those managing and developing the DAO's infrastructure.

Dependency on a decentralized consensus mechanism might be unsuitable if the business model requires quick responses to external shocks (paper 5 [38]). Conversely, member disengagement or low participation can become problematic in businesses where agility and swift decision-making are not critical. This often occurs when poorly designed incentives lead to excessive bureaucracy or stakeholder apathy.

Risk exists even if an organization is decentralized. For financial services, risk-taking is inherent to the business model and does not mysteriously disappear because one offers services in a decentralized manner and is, therefore, not subject to compliance. For financial services DAOs, a high level of professionalism is required, just as for traditional financial organizations.

3. **Is the market in which the DAO operates mature and competitive? (-)**

The scope and potential of DAOs for long-term survivability depends on the context of the surrounding environment in which it operates (paper 2 [48]). For example, a service might be subject to regulatory compliance, but the market in which the DAO operates cannot offer alternative solutions. This could be due to security or politics, lack of enforcement, high inflation, or cost base, where traditional finance cannot reach the market effectively, and the decentralized and autonomous features of DAOs make them viable as organizations.

Conversely, a highly competitive market with mature solutions to meet similar customer needs that are already abundant might make it very difficult for a DAO to survive. This dimension affects the relevance of DAOs as alternative organizational forms and explores the potential of the DAO to operate in various environments, adapting to technological and market changes.

4. **"Is the DAO sufficiently decentralized both technically, organizationally, and in its offering of services?" (+)**

Aligning to question number 1 in paper 5 [38], this question inherently asks if the organization is designed to promote decentralized governance. From papers 1 [47] and 5 [38], decentralization of control, Daft's organizational design dimension 2 [115], is key to DAOs, the De-Di form discussed in the background chapter, where trust and power are both distributed and decentralized, per Vergne [123]. This also aligns closely with Daft's organizational design dimension 1 – hierarchy of authority – which must be flat or non-existent in DAOs, and dimension 6 – personnel ratio.

Although DAOs can operate on various decentralized blockchains, the prevailing view is that permissionless public blockchains are most suitable. To fully leverage the decentralized nature of such blockchains, a DAO should have sufficient active members to ensure a breadth of perspectives that enhance decision-making and mitigate risks like decreased transparency or potential manipulation due to centralized control. The level of decentralization measures the absence of a central authority and the distribution of decision-making, as discussed in papers 1 [47] and 5 [38], ensuring at least 20 token holders for long-term viability. More recently, and notwithstanding the philosophical question of whether legal incorporation conflicts with the concept of a DAO, the US state of Wyoming passed a regulation requiring at least 100 members joined by mutual consent under an agreement for a decentralized unincorporated nonprofit association.

Other dimensions from paper 1 [47] that affect the level of decentralized governance are whether voting delegation is fair and unconditional, so there is no risk of manipulating reported delegation and evidence of broad voter activity. The question of decentralization is not only technical but also organizational and—for financial services DeFi – in the offering itself, as discussed above.

5. **"Can the organization integrate smart contracts into the governance processes?" (+)**

As discussed in the background chapter, question number 3 in paper 5 [38], and in the previous chapter, autonomy refers to censorship resistance, self-sovereignty, and independence in human-machine interaction.

Daft's organizational design dimension 4 – formalization – is high, measured by the formalization of rules and governance through code, and assesses how automation supports the lean operational model

while again aligning governance mechanisms with business objectives. The level of autonomy within a DAO impacts its ability to function without human oversight by incorporating governance and operational protocols into smart contracts, acting as autonomous agents. This can ensure predictable outcomes and enhance transparency, potentially minimizing decision bias.

However, careful consideration is needed due to the risks of inadvertently creating negative incentives or unnecessary complexity. With no hierarchical structure and employment laws inapplicable, every rule must be internally established, from travel expense limits to competitive constraints. This might result in a continuous influx of new rules every day. Further, the DAO's formalization of rules depends on the rules of the underlying blockchain, and these restrict the use case in terms of relevant DeFi service offerings to those that do not require high-frequency trading or real-time finality, as discussed earlier.

As mentioned, DAOs with specific goals might be fully automated, eliminating traditional organizational structures. In contrast, those with broader aims could benefit from a mix of automated and manual processes, adapting to changing conditions with scalable and stable system designs. This operational ambiguity is tied to formalization, Daft's design dimension number 4 and aligns to question number 3 in paper 5 [38], which is high.

From paper 1 [47], we identified that incorporating features into smart contracts allowing any group of stakeholders to lock, move, freeze, or thaw token balances on any or all addresses, as well as any potential for unilateral decision-making or modification of the smart contract code, poses potential security risks to the DAO and its stakeholders, thus impacting the overall level of decentralization. Additionally, the DAO code or applicable norms should establish accountability for decision-makers in a manner proportional to their power and responsibility.

6. **Is the operating cost competitive compared to agency cost in alternative organization forms? (+)**

Decisions in DAOs are often made through general voting after discussions on Discord or other forums, resulting in actions that cannot be swiftly executed, sometimes taking more than a week. This delay may become impractical for real-life situations, as any member can veto finalized contracts at the last moment at will. In addition, the democratic structure may be challenging in enhancing internal efficiency. With everyone potentially able to create their own roles and tasks, redundant personnel and inefficiency inevitably increase costs, questioning whether the DAO format is sustainable.

Assuming the cost is controlled, autonomy and automation objectives achieved through smart contracts are reflected in the organizational technology dimension – Daft's organizational design dimension 8 – where (permissionless) blockchain and smart contracts form the backbone of the DAO structure, suggesting a high level of technology reliance. As discussed earlier, other distributed ledger technologies than blockchain might be equally suitable for a DAO, as and when performance requirements drive this need (paper 3 [49]) and AI may further support competitive agency cost compared to more traditional organizations (paper 6 [52]), but a permissionless consensus method is still required to meet the overall decentralization requirement for DeFi DAOs.

The technical expertise and specialization required – organizational design dimension 3 – is medium, considering the extent of automation and the skills needed to design and maintain the lean operational infrastructure. Aligning to question number 2 above, but purely from a transaction cost perspective, DAOs with very wide and complex objectives might not be able to keep the cost of coordinating smart contract implementation lower than agency cost in traditional organizations [176].

7. **"Can the DAO operate a flat organizational structure with fluid work practices and dispersed, decentralized processes?" (+)**

Aligning with question number 4 in paper 5 [38], it is necessary to evaluate whether a flat organizational structure with fluid work practices and pseudonymous actors sometimes participating in unexpected manners can meet the organizational needs [118]. DAOs differ greatly from traditional hierarchical models, often featuring easy entry and exit and flexible roles. Such structures facilitate

decentralized decision-making and collaborative work across geographically dispersed teams, usually operating asynchronously and remotely.

The attractiveness of earning without a traditional job faces practical issues like potential tax liabilities due to unrecognized income without clear guidance on obligations. The transitioning to a DAO involves moving from conventional hierarchies to embrace distributed operations and governance, requiring technological and cultural shifts towards autonomy and remote collaboration. Financial services inherently require risk-taking, leading to the establishment of key controls to manage risk and resilience towards external shocks. Fluid work practices with a lack of accountability might result in inefficient or ineffective controls, potentially resulting in a risk level above the stated risk appetite and tolerance levels, which is unsustainable, as discussed in papers 1 [47] and 6 [52].

8. "Are the token-based incentives in alignment with the business model and culture?" (+)

Papers 1 [47], question number 5 in paper 5 [38], and paper 6 [52] all discuss the importance of token systems and economic incentives in managing distributed work within DAOs. These incentives are critical for aligning with or diverging from an organization's business model and culture. As discussed earlier, literature varies given human roles within DAOs, from essential individual contributions to advocating for complete automation. Stakeholders must carefully evaluate how token-based incentives influence engagement and define measurable goals to ensure effectiveness. Factors to consider include the potential for apathy, issues with pseudonymity, decision-making timelines, and the basis for rewarding contributions. If the DAO has a very wide objective function, it might not be easy to measure contribution appropriately. If, on the other hand, the objective function is very narrow, there is little need for human involvement, including voting and governance. From paper 1 [47], a 'fair' token launch designed to balance incentives and multilateral participation by rewarding non-colluding groups of agents for strategic participation and token distribution amongst active and passive stakeholders, which also impacts the organization's decentralization level.

Daft's organizational design dimension 10 around culture [115] is important in terms of high openness and transparent community management in DAOs, which must be able to support large communities, Daft's organizational design dimension 7. The case of CityDAO [177] shows that scaling and high demand pressure may be difficult to manage without a risk-aware culture supported with appropriate technology and properly designed mechanisms for contribution, incentives, and reward (paper 6 [52]). When assessing a DAO, one should evaluate its scalability and ability to incorporate many participants, its open and transparent culture, and how members coordinate and manage the organization as part of an internal control system to avoid reckless risk-taking.

The framework items above summarize how DAOs fit financial services. Considering the 10 organizational dimensions from Daft [115] together with the 2 organizational dimensions/attributes of DAOs in organizational context from chapter 6.1 and the 5 meta-themes from paper 5 [38], the detailed decentralization themes from the TIGER framework in paper 1 [47]; the regulatory positioning in paper 2 [48], 3 [49] and 4 [66] and the community and culture aspects in paper 6 [52] we may cluster the 8 dimensions from chapter 6.2 into four overarching themes to allow for broader generalization while capturing the essence and variability inherent in each.

Overall, we have now expanded on Daft's 10 theoretical dimensions of organizational design and adapted it to a total of 8 dimensions that we can use to assess DeFi DAO's suitability in regulated finance. We can cluster these 8 dimensions into 4 meta-themes: (i) Adaptability, (ii) Governance, (iii) Operations, and (iv) Community as follows:

- Adaptability to technological and market changes drives DAOs' alignment with complex regulatory environments as they engage in regulated financial services. It covers evaluation dimensions 1-3 above. It highlights DAOs' responsiveness to external shifts, adherence to high professional standards in regulated sectors, and the strategic integration of their operational goals with diverse legal frameworks. This captures their adaptability, flexibility, and the strategic planning necessary to navigate and leverage regulatory challenges effectively. As discussed earlier, a narrow objective function likely suggests full automation.

A very wide objective function covering complex financial services makes the DAO format potentially unsuitable as expert input to decision-making might increasingly be required. The organizational design attributes of Daft include Environment, Professionalism, Regulatory compliance, and Business objectives.

- The Governance theme addresses DAOs' foundational governance mechanisms, focusing on their flat hierarchical structure, decentralized decision-making process, and reliance on codified rules and protocols. It includes evaluation items 4-5 above and reflects the core organizational principles that dictate how authority and control are distributed within DAOs. The organizational design attributes from Daft include Hierarchy of authority, Centralization, and Formalization.
- The Operations theme captures how DAOs are operationally configured to leverage technological advances and specialized skills to manage tasks and roles efficiently. It includes evaluation items 6-7 above and emphasizes automation through blockchain technology, potential AI enhancements, and the lean operational model with minimal personnel overhead, illustrating the high level of automation and the need to reduce agency cost for long-term survivability, with medium specialization in technology as a prerequisite for the efficient and effective implementation of the decentralized structure. The organizational design attributes from Daft include Specialization, Personnel ratio, and Organizational technology.
- The Community theme covers evaluation item 8 above and focuses on the cultural aspects and the scalability of DAOs, highlighting the open and transparent nature of DAO community engagement and governance, alongside the ability of DAOs to scale and incorporate many participants, reflecting their inclusivity and communal approach, likely supported with generative AI as an internal control mechanism to sustain culture among a minimum number of members for long-term survivability. In contrast, the cost of coordinating democratic voting and active participation in very large DAOs might become too high, and someone, likely an influential token holder or someone with soft power will eventually take charge as large communities become increasingly difficult to manage centrally. The organizational design attributes of Daft include Culture and Size.

Consolidated, these themes capture the evaluation criteria outlined below in Table 6.2 with an impact marker.

#	Item	Impact
Adaptability		
1	Is the objective function and scope of service offering suitable for a DAO?	(+)
2	Can the DAO operate in an ambiguous legal environment without accountability?	(+)
3	Is the market in which the DAO operates mature and competitive?	(-)
Governance		
4	Is the DAO sufficiently technically and organizationally decentralized in its services?	(+)
5	Can the organization integrate smart contracts into the governance processes?	(+)
Operations		
6	Is the DAO's operating costs competitive compared to agency costs in alternative organization forms?	(+)
7	Can the DAO operate a flat organizational structure with fluid work practices and dispersed decentralized processes?	(+)
Community		
8	Are the token-based incentives in alignment with the business model and culture?	(+)

Table 6.2. Evaluation criteria for DAO suitability in regulated financial services.

6.3 Evaluation

In line with [178], I will now evaluate and apply the framework to three well-known DeFi protocols to exemplify how the assessment framework works for decentralized financial actors: (1) A business model representing a wide objective function (MakerDAO – a DAO with collateralized lending

including crypto and real-world assets, a governance token and a stablecoin soft-pegged to the USD). (2) Another protocol representing a narrow objective function (Uniswap – a decentralized exchange in the form of an Automated Market Maker (AMM)). (3) The third protocol is the same as we assessed in paper 1 [47] – Compound Finance, a decentralized money market protocol.

Even if three case studies are probably too small a sample to generalize more broadly from [78], we find it useful for confirmatory purposes when parts of the general framework are derived through a theoretical lens and the evaluation approach meets the requirements stipulated in [178].

6.3.1 Maker DAO

The Maker Protocol, often called the Multi-Collateral Dai (MCD) system, enables users to create Dai using collateral assets sanctioned by 'Maker Governance.' This governance is a community-driven and executed method for overseeing different elements of the Maker Protocol. Dai is a collateral-supported cryptocurrency in the form of a stablecoin algorithmically pegged to the US Dollar (an 'e-money token' per MICA). The whitepaper claims its low volatility makes it resistant to hyperinflation, providing economic liberty and prospects to individuals everywhere. Generating DAI through Maker requires taking out a loan over-collateralized with assets MakerDAO has approved through its governance processes. Governance transitioned from the Maker Foundation to MakerDAO in 2020 to decentralize control. In 2021, MakerDAO began integrating real-world assets into its vaults. A significant development in the project's governance structure came with the announcement of the "Endgame" roadmap in 2023, outlining a five-phase plan including a full rebrand, the introduction of new tokens "NewStable" and "NewGovToken," the establishment of specialized SubDAOs, the launch of AI governance tools, and incentives for governance participation. The plan culminates in the launch of a new blockchain, ensuring that MakerDAO's governance and operations remain decentralized, immutable, and self-sustaining.

6.3.1.2 An ideal profile of a collateralized lending/stablecoin DAO

Applying the framework, the ideal profile of a decentralized collateralized lending protocol might be characterized across the dimensions of governance, operations, community, and adaptability as follows:

Adaptability: Adaptability would be key for a decentralized lending/stablecoin DAO, especially given the dynamic nature of financial markets and the complex regulatory environments involved. Operating a multi-collateral lending protocol with crypto and traditional assets to fund stablecoins is a broad scope that includes complex macroeconomic controls to stabilize the coin against its peg and sophisticated monitoring techniques to manage collateral values vs. rates. Considering the organizational design criteria, this is potentially too wide an objective for a DAO. If such a DAO should be launched, it should maintain very high standards of professionalism and compliance to manage risk and align with financial stability expectations, even if decentralized. This includes being responsive to legal changes and market conditions to protect user assets and ensure the survivability of the DAO also in stressed environments. In terms of strategic positioning within the organizational space, this ideal lending-stablecoin DeFi DAO profile would fit a spot emphasizing decentralized governance, automated operations, a well-sized and engaged community, and high adaptability. This profile allows it to maximize the unique benefits of being a DAO while effectively managing the challenges of the lending needs, collateral, soft-peg-controls, and stabilization mechanisms. Such a DAO would be particularly effective when traditional banking is inaccessible or innovative lending practices can be securely implemented through blockchain technology at a competitive cost. Otherwise, the DAO could face significant challenges if it grows too large. Stablecoin might introduce systemic risks to financial stability, and defaults on collateralized assets could have spill-over effects on traditional finance. This risk becomes particularly concerning if real-world collateral defaults or the stablecoin loses its peg due to volatility in the broader cryptocurrency market.

Governance: Collateralized lending is complicated and will typically require a wide objective function to allow for diversification across different types of collateral. A lending/stablecoin DAO could thrive with a decentralized governance structure, where decision-making is distributed among all stakeholders rather than centralized. This could allow for more democratic processes and greater

stakeholder engagement in setting decision-making criteria for loan approval processes, interest rate settings, stability mechanism designs, collateralization policies, and other critical governance decisions. However, such activities are not trivial and could potentially carry high risk, so formalization should be high to ensure clear rules and protocols are in place to manage financial transactions through machine-readable instructions and to maintain security, trust, and resilience. Further, to avoid the associated agency cost with (too much) human curation, stringent eligibility/underwriting criteria should be enforced to ensure little to no flexibility in the application of the policy, ensuring that decisions are based on predefined, specific criteria to minimize discretion and ensure consistency in decision-making processes without ambiguity through the smart contracts defining the DAO. Otherwise, in a global lending protocol with many types of complex collateral and an algorithmically pegged stablecoin, thousands of token holders, no dominant actors, open voting mechanisms, risk and crisis, and cost management could potentially become a challenge.

Operations: Operational efficiency in a lending/stablecoin DAO would be best achieved with a high level of automation, minimizing human intervention in standard loan processing tasks through smart contracts and AI enhancements but maintaining a level of specialization regarding risk and reserve management. This reduces overhead costs and streamlines operations, allowing the DAO to operate leanly while managing scale efficiently. However, the smart contract design should include an emergency brake that can upgrade the protocol if unforeseen risk levels are experienced.

Community: The community size should be moderate to balance inclusivity with effective coordination and governance. If the protocol becomes very big, delegation should be encouraged to vote effectively and avoid voter apathy. As discussed in detail in paper 1 [47] such delegation of voting rights should be permanent, as it would otherwise breach the decentralization requirements. A culture that promotes transparency, trust, and mutual support is critical in a financial setting to foster a strong, engaged community that understands and embraces risk management and actively participates in governance and oversight, contributing to the DAO's resilience and reliability.

6.3.1.3 Assessing MakerDAO vs Ideal Profile

Table 6.3 shows the evaluation results of MakerDAO vs the ideal profile.

#	Item	Impact
	Adaptability	
1	MakerDAO's objective includes (i) multi-collateral approval and management across traditional and crypto assets and (ii) a stablecoin algorithmically pegged to the USD. The 'endgame' plan appears very wide and has potentially unknown implications, including the launch of a new blockchain. This is a wide objective function, like creating an entirely new economy. The DAI has been operational for a short period of 4 years, and it has lost its peg several times since then, most recently in 2023, due to volatility in the general crypto market [179]. Such a wide objective appears potentially too wide for a DAO with fluid work practices and pseudonymous actors to manage risk effectively. This is likely also why the Endgame plan introduces the concept of subDAOs, further complicating the ability to navigate in a flat and decentralized organization.	(-)
2	MakerDAO operates in mature and immature markets with a stablecoin pegged to the world's reserve currency, the USD. Its collateral is increasingly traditional assets. The EU MICA regulation regulates e-money tokens (EMT) (as a stablecoin like DAI would be considered under MICA), as detailed in papers 1 [47], 2 [48], and 3 [49]. MICA is only coming into effect at the time of writing this dissertation. If the EU regulators determine MakerDAO to be sufficiently decentralized, the DAI can be offered to the public in the EU without compliance. However, suppose a crypto asset is deemed to pose a systemic risk or otherwise infringe the regulation. In that case, national competent authorities can use their powers to close distribution channels (Crypto Asset Service Providers (CASP) who service the regulated crypto assets), cfr MICA article 94. This, in effect, means that the authorities can close the market, also for a fully decentralized stablecoin (EMT).	(-)

	As of May 25, 2024, the circulating number of DAI is approximately 3,7Bn, and equity in the surplus buffer amounts to 47m [180]. MICA requires an own funds capitalization requirement of the higher of €350,000 or 2 pct of circulating EMT. If the EMT is 'significant,' the capitalization requirement is 3 pct. 'Significance' is determined in MICA if two out of the following three criteria apply: >€5Bn circulating volume, >10m holders, >2,5m daily transactions/€500m in daily volume. At the time of writing, Maker only meets one of these criteria – the circulating volume. Using an exchange rate of 0.93 DAI (USD)/€, the required capitalization of MakerDAO should be approximately €69m (if deemed significant, app €103m). With its current equity position of approximately €47m based on the reported surplus buffer, MakerDAO appears under-reserved with some 32 pct. This is a material gap and may lead to regulatory enforcement actions when MICA comes into full effect later this year. Again, this decision does not need to assess whether MakerDAO meets the decentralization test; it is an enforcement option built into MICA to close systemic or unacceptable risk, like the OFAC's enforcement actions against the Tornado Cash smart contracts, as discussed in paper #2. It appears likely that such a level of under-reservation of a systemic EMT will result in regulatory action. In summary, the regulatory pressure and legal complexities are very high, making the DAO structure potentially unsuitable for this business scope.	
3	MakerDAO operates globally with what might be considered an alternative monetary regime. This market is mature as all countries have a monetary regime. Yet, some regimes are not working due to political instability and high inflation, so the value proposition of offering an alternative financial system is compelling in those countries. Whether MakerDAO's business model is suitable from a competitive perspective is difficult to assess. Still, it competes in competitive and mature markets as well as other less mature and competitive markets, where it is likely to have more success. Further, it has only partially implemented an alternative financial system with significant shortcomings remaining [181]. So, the answer to whether it operates in a competitive and mature market is 'maybe.'	(?)
Governance		
4	Maker prides itself on being the first real truly decentralized protocol in decentralized finance. Organizational decentralization: As many scholars have already analyzed and evidenced, governance centralization and large token holders influence the DAO significantly in voting [149][156][178], and it is questionable whether organizational decentralization of control is present. The evidence provided by the scholars suggested that MakerDAO perhaps operates more like an unincorporated partnership, like a Ce-Di franchise structure, than a De-Di structure, the true DAO form. It goes beyond the scope of this evaluation to determine if the new Endgame plan with subDAOs has changed this picture materially, but from [180] It appears that the 'Big Fish', the founder who dominated the DAO voting through the transition to the new plan, has (re)delegated its/his token holdings, as shown in Figure 6.1 below. The governance's weight has shifted over time, with the old fish morphing into big fish from January 2021 to July 2023.	(-)

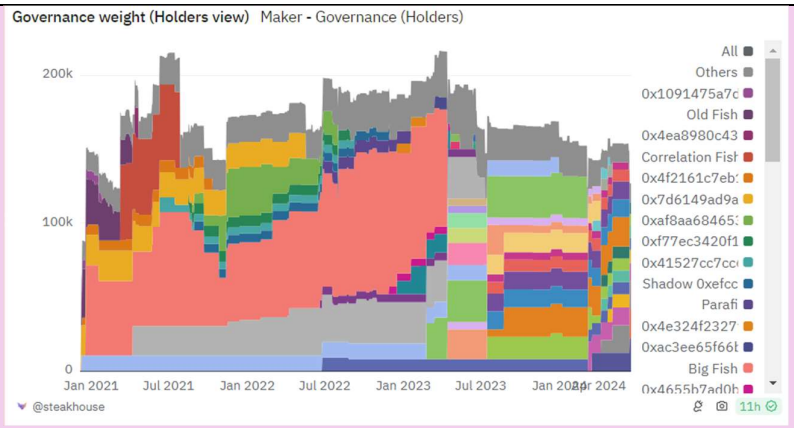

Figure 6.1. MakerDAO governance weights over time.

Technical decentralization: The DAO operates on the Ethereum blockchain. Ethereum governance is transparent and involves a large, diverse community. [183]. However, a relatively small group drives core development and protocol changes in Ethereum, raising centralization concerns. Dependencies on external services further complicate the decentralization narrative. So, while Ethereum is largely decentralized at the time of writing, certain aspects reveal centralization tendencies that need continuous monitoring and management.

In terms of providing any special rights in the smart contracts to any central authority, the licensing of MakerDAO's code consists of 312 repositories [184] that appear mostly open source but with certain conditions and variations depending on specific components. These licenses include the GNU General Public License (GPL). MIT License (MIT), Creative Commons License (CC), and the Affero General Public License (AGPL) are designed to ensure that the software remains free and open for anyone to use, modify, and distribute. Some repositories, such as the developerguides and developer.makerdao.com, are under Apache License from the Maker Ecosystem Growth Foundation that retains copyright. Other repos such as the developer-portal, the simple-dex-UI and nextjs-daijs-dai-ui-example, which appears to be another UI, are under similar licenses, but to the Maker Ecosystem Growth Holdings, INC. These companies seem to be Cayman Island based entities, the latter of which has been the subject of several (dismissed) lawsuits against the Maker protocol; from a web search, it appears to have housed a conglomerate of subsidiaries but is now known as Metronym, Inc. Yet other code repos are under license to MakerDAO, such as the staxx and testchain-stack-helloworld code repositories, that appear to contain elements of the testchain environment for the protocol. A few repositories like testchain-deployment, sourcecred, which was an attempt to score reputation for incentives, and api.oasisdex.com, the price contracts, and auction-demo-keeper, which is code examples for liquidation auctions are under Apache licenses but without anyone holding the copyrights.

Offering decentralization: According to the Maker website, multi-collateral DAI is created through vaults only. A user creates a vault through the protocol's Oasis Borrow portal or a community-created interface such as Instadapp, Zerion, or MyEtherWallet by depositing a specific type and amount of collateral, which will be used to generate Dai. Once funded, the vault becomes collateralized. The vault owner then initiates a transaction and confirms it in their unhosted cryptocurrency wallet to generate a specific amount of Dai, with the collateral remaining locked in the vault. To retrieve some or all of the collateral, the vault owner must repay the generated Dai and the Stability Fee, which accrues continuously and must be paid in Dai. After Dai is repaid and the stability fee settled, the vault owner can withdraw all or some of the collateral back to their wallet. The vault remains empty until the owner decides to make another deposit. DAI is distributed across the crypto

	ecosystem; no central actor controls significant distribution. The copyright issues mentioned above do not appear to include the community-created interfaces, only the specific ones mentioned, such as the Oasis API. Some public reporting (150,151) suggests the bulk of traffic into the protocol is going through the Oasis app, now rebranded Summer.fi, which, according to Reddit, is controlled by the same multisig token holders that control the Oasis app. It goes beyond this evaluation for a full forensic analysis of this relationship; suffice to mention that to the extent UI is controlled by centralized actors in the protocol, the offering is likely, not decentralized. Aside from this, a substantial volume of DAI sits on DeFi protocols Uniswap v3 and Curve, as these are not associated with MakerDAO in terms of ownership. In the assessment, it is also worth mentioning that the MKR governance token does not receive protocol fees directly but benefits indirectly via the protocol's burn mechanism from (i) stability fees from users who lock up collateral to generate DAI that accumulate in the system, and (ii) once the collected fees reach a certain threshold, they are used in a process called a Surplus Auction, where excess DAI is sold for MKR tokens. The MKR tokens obtained from these auctions are then burned (destroyed), reducing the overall supply of MKR in circulation, thereby increasing the value of MKR. MKR is listed on several decentralized and centralized exchanges.	
5	MakerDAO's service offering does not require high throughput or real-time finality, and the DAO has extensively implemented smart contracts in its governance and operations, so that would be a yes to the ability to apply smart contracts in its governance process.	(+)
	Operations	
6	It is difficult to conduct a full analysis of whether MakerDAO is cost-competitive in the long run, as MakerDAO is going through the Endgame transition with the implementation of new subDAOs and transforming the collateral to real-world assets, but in the Spring 2022, as discussed earlier, it was deemed not to be cost-effective for its purpose and needed a significant organizational revamp, the Endgame proposal [174]. Yet the DAO appears profitable since August 2023 (145), in 2024, with average monthly profits of nearly USD 10m. As discussed above, the DAI is potentially under-reserved, affecting profitability overall. It is clear, though, that if MakerDAO is not decentralized, it operates a redundant decentralization layer, which is not very economically meaningful.	(?)
7	MakerDAO has historically operated a very flat organizational structure with fluid work practices. With Endgame, the DAO has taken on a more hierarchical structure organized into subDAOs, which resemble more traditional forms of organizations yet is still very much guided by formalized rules and smart contracts. The answer is 'maybe.'	(?)
	Community	
8	The MakerDAO community is very much alert to token-based incentives, but the transformation into what is now the Endgame led to some significant changes that were not aligned with everyone's vision of MakerDAO. That is natural when organizations grow; this transformation has not materially changed the token-based incentive model. So, the token-based incentives align with the business model and culture.	(+)

Table 6.3. Evaluation of MakerDAO.

In summary, MakerDAO's objective function appears very wide for the DAO form to be suitable as an organizational form. The DAO potentially runs into increasing regulatory pressure if it becomes systemic and, in any respect, due to being heavily under-reserved. It appears to have recently failed in organizational decentralization. From a regulatory perspective, according to MiCA, decentralization must be assessed at a point in time, i.e. the time at which the regulated service is made available. With MiCA coming into effect June 30, 2024, for the parts covering stablecoins, this means an assessment

will be undertaken in the second half of 2024. While MakerDAO might again be on a path towards decentralization as part of the Endgame plan, overall, it is questionable whether the DAO format is suitable for the business of the protocol from a systemic perspective as determined by the authorities.

6.3.2 Uniswap

Uniswap Protocol [41] is the largest non-custodial exchange in DeFi [185] with TVL of more than USD 8Bn and a fully diluted market value of more than USD 11Bn. It is the third highest fee-earning decentralized application (dApp) in DeFi, with an estimated annual fee income above USD 700m. Uniswap Labs is the company behind developing the Uniswap protocol and its accompanying web interface.

Uniswap does not present itself as a DAO. Instead, it presents itself on its website and in regulatory matters [109] as three distinctly different elements – (i) the Protocol, (ii) the Interface, and (iii) the Governance.

i. The Uniswap Protocol consists of a series of persistent, non-upgradable smart contracts that establish a decentralized exchange in the form of an automated market maker (AMM), facilitating peer-to-peer market making and the swapping of ERC-20 tokens on the Ethereum blockchain. At the time of writing this dissertation, there are three iterations of the Uniswap protocol. Versions 1 and 2 are open source. Version 3 is also open source but includes minor modifications, which are accessible for review. Uniswap Protocol uses the concept of a (smart) factory contract that controls the fee tiers in each version of Uniswap. All contracts have an owner, which UNI token holders initially control through UNI governance, but the owner cannot halt the operation of any of the core contracts [186]. As a set of smart contracts, once deployed, each version of Uniswap is designed to operate indefinitely with 100% uptime for as long as the Ethereum blockchain continues to exist.
ii. The Uniswap Interface provides a user-friendly web interface that facilitates interaction with the protocol. Traders can use aggregators, alternative user interfaces (UIs), or go directly through the smart contract to make swaps. According to [187] The Uniswap Interface is used in the app for 25 pct of the volume traded on the Uniswap Protocol, down from 50 pct a year ago. Interestingly, Uniswap Labs has recently increased its fees to use the Interface, which is likely to drive traffic away, showing increased decentralization of the offering. This was action just after Uniswap Labs received a regulatory notice [188].
iii. Governance is managed through a system enabled by the governance token UNI. The protocol incentivizes users to sustain liquidity in its pools by rewarding them with parts of transaction fees and newly created UNI tokens for their participation. Uniswap launched its governance token through a retrospective airdrop in September 2020. This strategic distribution was aimed at anonymous wallet owners who had previously engaged with the platform by swapping tokens or providing liquidity [35]. UNI token holders exercise governance over the Uniswap exchange, wielding the authority to vote on decisions concerning the management of treasury funds and modifications to the exchange's regulatory framework. UNI governance also can add additional fee tiers and it has the power to transfer ownership to another address. Uniswap was the first DeFi protocol to pass USD 100 Bn in volume. As of May 11, 2023, the UNI token ranks among the top ten crypto assets by market capitalization, yet trading only at USD 7, well below its peak of more than USD 42, but still well above its initial launch price of USD 5.

When Uniswap issued the UNI token in September 2020, it introduced a formalized governance system in which UNI token holders can vote on key decisions and proposals related to the protocol's development and management. These decisions include changes to the protocol, usage of treasury funds, and other amendments. The governance system allows any UNI token holder to propose changes, provided they meet certain thresholds of token ownership, which further emphasizes its decentralized nature. This resembles a DAO, as token holders collaboratively make decisions about the platform's future rather than having a central authority or a limited group of decision-makers through a multi-sig scheme that allows users to manage the Protocol’s wallet in the blockchain

network. This system is outlined in Uniswap's documentation and governance forums, where community members discuss and vote on proposals. Hence, even if Uniswap has deliberately designed its functions not to mirror a 'traditional' DAO structure, it uses blockchain technology to enable governance and decision-making through its community of token holders, who also refer to Uniswap as a DAO in their forum. For these reasons, I will view the combined Protocol and Governance similarly to a DAO in evaluating whether it is a 'fit' while reflecting on the role of the Interface separately.

6.3.2.1 An ideal profile of a DEX in a DAO context

A DEX has a very narrow objective function, as the only thing that matters in an exchange is volume, which will increase liquidity and reduce slippage. This influences the ideal profile towards full decentralization and automation through smart contracts, as also discussed in the case of [169] and in paper 5 [38], without needing a DAO as a supporting organization.

Adaptability: Like lending DAOs, adaptability is critical for a DEX, especially in rapidly changing financial markets and a complex regulatory environment. A DEX must be responsive to technological advancements and regulatory changes, ensuring compliance with legal requirements across different jurisdictions. This involves maintaining high standards of professionalism, especially in customer support and dispute resolution, and adjusting operational goals to align with evolving market and regulatory conditions.

Governance: A DEX would benefit significantly from a highly decentralized governance model to promote trust and transparency in its operations. This model would allow users to have a direct say in important decisions, such as updates to the protocol, fee structures, and listing new tokens, reflecting a flat hierarchical structure with minimal centralization. High formalization is important to establish clear, codified rules and smart contracts that ensure fair and secure trading.

Operations: Operations in a DEX should be highly automated, relying on smart contracts to execute trades directly between users autonomously without intermediaries. This setup reduces operational costs and enhances efficiency while also minimizing human error and the potential for fraud. Specialization in technological deployment, such as implementing efficient and secure blockchain protocols, is critical.

Community: A DEX's community should be extensive to ensure liquidity and a vibrant trading environment. A larger community also supports better price discovery and more trading pairs. The culture of this community should encourage active participation, feedback, and collaborative decision-making, fostering a sense of ownership and alignment with the exchange's goals and values. Incentives should focus on driving traffic to the DEX to improve the volume and, thereby, liquidity, the key objective.

6.3.2.2 Assessing Uniswap vs the ideal DEX DAO Profile

Table 6.4 shows the evaluation of Uniswap vs the ideal DEX DAO profile.

#	Item	Impact
	Adaptability	
1	Uniswap's design of three separate structures suggests the founders have thought cleverly about the organizational design. Its narrow objective function appears well aligned with the Protocol smart contract factory, resulting in a 'yes.'	(+)
2	Uniswap has established itself in the US after carefully considering the legal environment, and it has designed its business model carefully given this, so far with a positive result. Indeed, it appears well equipped to defend itself in the most recent regulatory action [109], arguing (i) the Protocol is an AMM technology that is not controlled by any single entity, (ii) the Interface is one of many applications enabling users to access the Protocol, (iii) the Autorouter, managed by the Interface, is an open-source tool that solely recommends the best trading path and does not distribute anything, (iv) the UNI token is a governance token that allows holders to control limited aspects of the Protocol, (v) the AMM it is not an exchange in the	(+)

	terminology of what constitutes such (under US law where the regulatory action is served), (vi) there is no securities offered by any of the three elements, and combined, that the regulators have previously confirmed it is not violating any rulebook. Uniswap Labs also won another recent case, as the judge found that whether the underlying protocol could be held liable for faulty issuance of tokens on the AMM smart contract was a question better decided by Congress, not the courts [189], [190]. With this track record in mind, Uniswap appears well-equipped to operate in a potentially ambiguous legal environment.	
3	Like MakerDAO, the three protocol elements operate globally, including mature and immature markets, but with a highly competitive product that scholars claim creates deeper markets and better price alignment [191] at less cost than traditional exchanges [109]. Contrary to MakerDAO, Uniswap does not appear to pose a systemic risk. If it is sufficiently decentralized, it will likely be able to operate without compliance, giving it a further competitive edge over incumbents. Perhaps surprisingly, Uniswap was not included in the enforcement action taken by the authorities in India when they blocked the websites of 8 crypto exchanges due to lack of registration [192], suggesting Uniswap elegantly maneuvers the regulatory space in both mature and emerging markets.	(+)
	Governance	
4	Whether Uniswap is decentralized is important in view of the US Howey test and EU MICA, cfr paper 2 [48]. If not sufficiently decentralized, the governance and protocol setup may be considered a security offering under US regulation, and in the EU, with MICA coming into effect shortly, the service offering will require licensing, a compliance organization, and regulatory capital as a CASP. Organizational decentralization: The initial token launch was rather concentrated, with more than 40 percent allocated to early adopters, and a year later, 23 addresses controlled more than 50% of the active token supply [35]. As discussed earlier, 23 token holders controlling the voting might be considered sufficiently decentralized and acceptable for the long-term survivability of a DAO. More recently, in 2023, when voting on bridging Uniswap to a new blockchain, a significant opportunity for the chosen software provider, venture capital firm Andreessen Horowitz (a16z), who was also a seed investor in LayerZero, a potential software developer suitable for the job, deployed 15m UNI tokens against the original proposal. Although A16z's votes did not ultimately prevent the approval of the BNB deployment, they nonetheless raised concern about the venture firm's continued influence over Uniswap's governance system. Scholars [157] have questioned the validity and long-term feasibility of the one-token-one-vote model for effective DAO governance. Still, as matters stand, Uniswap is likely sufficiently organizationally decentralized at this point in time. It is also worth mentioning that Uniswap recently passed another vote on improving voting participation in delegation [193]. Technical decentralization: Like MakerDAO, Uniswap operates on the Ethereum blockchain and other blockchains. When Uniswap Labs launches its new versions, it retains licensing rights for several years. [194] outlines the licensing for the upcoming v4, expected in Q3 2024. For the current v3, a similar license handed over the rights to the community via the Governance protocol on April 1, 2023. So, at this point in time, Uniswap is technically decentralized to the extent the organization is considered decentralized. However, when the new v4 is launched, this changes. This approach to versioning the protocol indicates that Uniswap Labs is a central dominating factor in the entire protocol. Offering decentralization: Aside from the question of whether the distribution of governance tokens is a securities offering or not, the distribution of the service offering to the Protocol was controlled by Uniswap Labs' Interface with more than 50 pct until a year ago. This would be considered centralized, but as mentioned earlier, it is now less than 25 pct. With the recent fee hike for using the Interface, the	(+)

	traffic to the Protocol will likely decentralize further.	
5	Uniswap is a prime example of operating a smart contract 'factory' concept and governance minimization. However, a forum blog states, "free-riding and apathy remain existential risks to the Uniswap Protocol's sustainability. Less than 10% of the circulating UNI is used to vote on a given proposal. Further, a large portion of existing delegation is 'stale.' As of February 1, 2024, 14 of the top 30 delegates by voting power had not voted over the last ten proposals, and only 7 of these delegates have ever created a proposal" [195]. This suggests a lack of engagement in the community, which I will touch upon below under items 6 and 8.	(+)
	Operations	
6	Uniswap version 2 introduced a flat fee of 0.3% on all swaps and an optional 'fee switch' allowing the protocol to take a percentage of the collected fees, potentially distributing them to UNI token holders as retained earnings. With the launch of Uniswap version 3, the fee switch option was retained, but different fee tiers were added, ranging from 0.01% to 1%, depending on the relative stability of the trading pairs. Most pairs are charged a standard fee of 0.30%, stable pairs are charged 0.05%, and the most stable pairs incur a 0.01% fee, while high-risk or "exotic" pairs can be charged up to 1%. The decision to activate the fee switch requires approval from UNI token holders through an open vote in the protocol governance forums. In June 2023, a proposal to enable protocol fees on all swaps was narrowly defeated, with 45.32% 'No' against 42.34% 'Yes.' Another attempt in February 2024 to turn on the fee switch and distribute rewards among UNI holders also failed, suffering another setback in a snapshot vote with almost 2500 votes on March 8, 2024 [196], representing 55m UNI when there were approximately 600m UNI in circulation. These multiple rejections suggest that the Uniswap community is cautious about making significant protocol changes, resulting in all revenues to date being paid to liquidity providers, with the Uniswap DAO not retaining any revenue. However, another vote in March 2024 gauged community sentiment to continue working towards a protocol fee to the DAO to revitalize and enhance Uniswap's governance system by encouraging active, committed, and thoughtful delegation. This proposal received 100 percent support [197], again with almost 2500 votes participating, representing 50m UNI [195]. It is difficult to get a clear view of the DAO on the cost side. Still, with a narrow objective function, a very high level of automation, and no significant capital requirements, as there is no counterparty risk in the settlement on-chain, the DAO should be very profitable, as the market value of UNI also suggests.	(+)
7	In line with the 'governance minimization' ethos, Uniswap operates with a flat organizational structure characterized by fluid work practices and decentralized processes. Uniswap Labs has 135 associated members listed on LinkedIn, while the Uniswap Foundation has 13. The Protocol's governance is intended to be directed by its users, prompting the Uniswap Foundation to fund an ethnographic research project in 2021 [198] to explore the Uniswap community's culture. This study observed interactions on Discord and Slack from the launch of 'Unisocks' at Devcon 4 in 2018 through the bull market ending in 2021. Several themes emerged from the research: (i) The tension between Uniswap Labs' need to offer a competitive product and its goal of fostering a thriving community culture; (ii) The conflict between viewing community members as end-users versus treating them as stakeholders, discussion participants, or governance leaders, evidenced by support requests dominating Discord conversations; (iii) The view that governance should involve all participants in discussion, contrasted by the disjointed and inaccessible structures and processes of governance for the average user. Additionally, the Discord channel was found to be disconnected from other areas of Uniswap protocol and governance, with the Uniswap Labs team notably absent from the community. This absence is an inherent outcome of the decentralization and	(+)

	autonomy-focused vision underpinning governance minimization. Hence, while Uniswap exemplifies fluid work practices and a lack of traditional organizational leadership, it also faces cultural challenges, which will be further discussed below.	
	Community	
8	As discussed in items 5, 6, and 7, Uniswap's community and culture face significant challenges, with a recent proposal aiming to invigorate and strengthen Uniswap's governance system. This indicates that Uniswap's culture is underdeveloped, with community interactions more akin to a help desk than a fully functioning DAO with substantial off-chain governance. This misalignment suggests that the token-based incentives do not perfectly align with the business model and cultural requirements needed to operate as a DAO. Hence, a fully automated exchange might be more suitable for Uniswap, aligning with its narrow objective function.	(-)

Table 6.4. Evaluation of Uniswap.

In summary, Uniswap operates at this point as a fully decentralized and distributed exchange, aligning with its narrow objective function. It does not officially present itself as a DAO, and Uniswap Labs has designed the platform architecture to enable user governance while reducing its own role in terms of distribution. While the SEC and US courts have yet to determine whether Uniswap Labs should be classified as a broker/dealer and EU authorities whether it is a CASP under MICA, the platform appears sufficiently decentralized now. However, two important remarks must be added: (i) Uniswap Protocol and Governance minimization policy is potentially unsuitable for a DAO because it does not sufficiently address off-chain community elements, supported by its narrow objective function. Consequently, there is no need for an organization to support it or a protocol fee to fund such an organization. (ii) The role that Uniswap Labs takes in the future direction of the Protocol, its initial allocation of a material amount of governance tokens to itself, founders, and early investors, and the role Uniswap Labs continues to play in the offering suggest a level of soft power that directs the overall assessment towards lack of sufficient decentralization.

6.3.3 Compound Finance

Compound Finance ('Compound') is an open DeFi lending platform that enables users to stake and earn interest on their cryptocurrency holdings. It was established in 2017 to provide money markets for blockchain assets. Using the TIGER framework, we assessed the protocol's decentralization level in paper 1 [47] and found it 'sufficiently decentralized' although somewhat concentrated in voting power. In Compound, funds deposited by lenders are kept in smart contracts called liquidity pools, with interest rates dynamically adjusted according to supply and demand. The protocol utilizes smart contracts to automate the calculation of interest rates and loan distribution, removing the need for intermediaries. As detailed in paper 1 [47], the Compound protocol can be configured or upgraded solely by COMP governance token holders or their delegates. The voting process encompasses changes to collateral parameters, interest rates, the introduction of new markets, and various system characteristics. A COMP token equates to one vote, and an address needs to hold at least 25,000 COMP to put forward a proposal. COMP owners can delegate voting power to themselves or any other Ethereum-compatible wallet. Additionally, COMP holders cannot vote or create proposals unless they have delegated their tokens to themselves or another address. Hence, delegation is an important aspect of the protocol.

While Compound and MakerDAO are DeFi protocols, they serve different purposes and operate through other mechanisms. Compound's primary focus is facilitating general lending and borrowing of a wide range of cryptocurrency assets on the Ethereum blockchain, employing liquidity pools with dynamically adjusted interest rates based on supply and demand. This is very much like traditional money market funds. At the time of writing, Compound does not accept real-world assets. In contrast, MakerDAO centers on creating and stabilizing its DAI stablecoin, utilizing vaults and stability fees. Both platforms require over-collateralization to mitigate risk, yet their approaches to collateral management reflect their differing objectives. Governance within these protocols is also distinct, with

Compound utilizing COMP tokens and MakerDAO employing MKR tokens, each governing their respective platforms in alignment with their unique missions.

There is, however, an important nuance to the comparison between Compound and MakerDAO: Operating a multi-collateral deposit vault system that includes real-world assets and a stability mechanism to peg a stablecoin like DAI to fiat currency is inherently more complex than managing a decentralized lending and borrowing protocol with crypto assets. In this regard, Compound functions as a sophisticated marketplace for lending and borrowing various cryptocurrencies. It involves dynamic interest rates and liquidity management, which, while complex, are focused primarily on matching lenders and borrowers within a decentralized framework. This model is broad in its asset support but relatively straightforward regarding its operational mechanics compared to MakerDAO. MakerDAO's system, on the other hand, requires the maintenance of stability for its DAI stablecoin, which involves intricate mechanisms for collateral management, real-world asset integration, and stability fees. Ensuring that DAI remains pegged to the US dollar introduces additional complexity encompassing monetary policy-like interventions and risk management strategies.

Compound does not present itself as a DAO. This was assumed to be the case when we researched paper #1. In this regard, Compound utilizes the governance token called COMP, which allows token holders to propose and vote on protocol changes, including modifications to system parameters, adding new assets, and other material decisions. This decentralized governance structure is very similar to a DAO, with the decision-making process managed collectively by the community of COMP token holders, ensuring no single entity controls the protocol. The core functions of Compound, such as lending, borrowing, and interest rate adjustments, are managed by smart contracts operating autonomously based on predefined rules, reducing the need for centralized intervention. Therefore, its governance model and autonomous operations align closely with the definition of a DAO we presented earlier.

6.3.3.1 The ideal profile for a money market DAO

A decentralized lending marketplace DAO should have a semi-narrow objective function, but in other respects, the profile is like a DEX.

6.3.3.2 Assessing Compound Finance against the ideal lending DAO profile

Table 6.5 shows the evaluation results of Compound Finance vs the ideal profile.

#	Item	Impact
	Adaptability	
1	While Compound's objective function is broad regarding the range of assets and financial activities it supports, MakerDAO's objective function can be seen as wider and more complex due to its multifaceted approach to collateral management, stability maintenance, and integration of real-world assets. Thus, Compound's role is more akin to a decentralized financial marketplace. In contrast, MakerDAO's role involves a wider array of functions, including those akin to a central bank's responsibilities within the DeFi ecosystem. Compound does not take on interest rate or asset-liability risk, and there is minimal credit risk as loans are over-collateralized and liquidation is automated, like in MakerDAO. In this context, Compound's objective function appears suitable for a DAO.	(+)
2	As MakerDAO and Uniswap, Compound operates in regulatory uncertainty, and the comments made for those around MICA apply equally to Compound.	(+)
3	Similarly, Compound operates globally across mature and emerging markets.	(?)
	Governance	
4	We assessed Compound to be sufficiently decentralized, but with some room for improvement on the TIGER dimensions (i) Governance and (ii) 'Reputation and the Impact of Soft Power on Decision-Making Processes' due to a somewhat concentrated delegated token holder representation and lack of dispute resolution mechanism (paper 1 [47]). Organizational decentralization: In the same analysis, we found that the	(+)

	shareholders of Compound Labs and early investors represented a limited number of verified independent agents who controlled around 45 pct of the COMP tokens. The number of proposals is around [199] proposed in May 2024, a new governance working group mentioned that active voters with more than 25,000 COMP now count 13 verified independent actors. Quorum is still at 400,000 COMP. Also, we found an average of 2.3 proposals per month proposed. This has increased significantly to now close to 9 proposals per month, but a closer look suggests more than 70 pct of proposals in these past six months were proposed by Gauntlet, the risk management advisor. Considering this most recent period coincided with the decommissioning of Compound v2 as part of the migration to v3, the reality appears somewhat unchanged. In this period, the average voting participation was around 500,000 COMP, equivalent to approximately 6 pct of the circulating tokens. According to [200] there are slightly more than 200,000 token holders in Compound, of which 98.66 pct hold less than USD 1.000 worth of COMP tokens. Whales hold 53.26 pct of tokens and are defined as token holders with more than 1 pct of the circulating supply, now 8,3m or 83 pct of the total supply. This means a high concentration of voting power, as we also observed in paper #1, yet it still appears non-collusive. Almost 87 pct. of token holders have held their holdings for over a year. While the dispute resolution mechanism is still not implemented, the number of active delegates and proposals has now increased, but likely just temporarily. Organizational decentralization is viewed as having a similar level since paper #1 and appears stable, although not at the expected level, and the protocol suffers from a lack of participation. Technical decentralization: Compound operates on the Ethereum blockchain, including layer 2 chains. Again, while Ethereum is mostly decentralized, certain centralization aspects require continuous oversight. The Compound github repo contains 77 code repositories [201]. The Comet repo contains Compound v3, the money market protocol in production on-chain at the time of writing. This is copyrighted to Compound Labs as a business source license, like the Uniswap approach, however in this case, the business license transfers to an open-source GNU General Public License on December 31, 2025, the fourth anniversary from launch, or an earlier date as specified in v3-change-date.compound-community-licenses.eth. Until then, in what can be considered the Pre-change date, Compound Labs retains significant control, especially regarding commercial use, modifications, and redistribution. They can enforce the terms and require commercial licenses for non-compliant uses. Permitted use should be registered on the ENS service [202]. At the time of writing, the ENS reports, one permitted user, the Compound wallet per Etherscan, and no earlier change date was noted. The Compound protocol and several other reports in the Github are also under business source license to Compound Labs, but in a different form - BSD 3-Clause "New" or "Revised" License, which permits usage without approval, as long as the copyright is noted. This indicates that Compound Labs has full control of the money market dApp and has retained copyright on several components used in the Protocol. Hence, the Protocol is not technically decentralized. Offering decentralization: The smart contracts in Compound Finance can be accessed through Compound Finance’s website using non-custodial wallets like Metamask, but the community has built several other integrations, including Coinbase, Ledger, Anchorage, Bitgo, and Fireblocks. The Comet extensions is a repo on Compound’s github that holds the required extensions for integration with Compound v3. Of the 6 contributors, 4 are verified individuals in Compound Labs. So, although there appears to be no dominant actor in the offering distribution, the UI is owned and controlled by Compound Labs. Aside from this, the COMP governance token itself is listed on several decentralized and centralized exchanges. Like the UNI governance token but different to MKR governance token, the COMP token does not receive protocol fees indirectly, only token value appreciation.	

5	Compound was the first DeFi protocol to issue a governance token and has been replicated by many others. The extensive use of smart contracts is discussed in paper #1. It uses financial and professional services firm Gauntlet for risk management.	(+)
Operations		
6	Compound Labs now has 23 associated members on Linkedin, four 4 more than we found in paper #1. Again, the organization seems fairly stable compared to the review in paper #1. Annualized fees are above USD 28m [203], which seems highly profitable given the high level of automation. The market cap of around USD 600m equals around 21X revenues, which is higher than for Uniswap (USD 9,8 Bn) at 12,6X annual revenues. MakerDAO market cap (USD 2,6Bn) equals 31X annual revenues.	(+)
7	As we found in paper 1 [47], Compound's fluid work practices and flat organizational structure with dispersed, decentralized processes appear not to be an issue.	(+)
Community		
8	As discussed above, the token-based incentives appear to work. Compound Labs' founders are more active in the Discord and forum communities than those at Uniswap, although not in any particular dominant position, as in MakerDAO.	(+)

Table 6.5. Evaluation of Compound Finance.

In summary, the objective function of Compound appears suitable for a DAO. The protocol seems organizationally decentralized, yet not to the extent envisioned when we assessed it in 2022, where it was viewed as on a path toward decentralization. Other scholars [117] have reached a different conclusion on the decentralization level in Compound, based on similarities in voting patterns among the whales. Considering the regulatory developments and the view that decentralization must also occur in the service offering, not just technically and organizationally, Compound has not progressed further on decentralization. On the contrary, Compound Labs controls the copyrights of v3, impacting the protocol significantly. While Compound with a TVL of around USD 3Bn is only around 3 pct of the TVL of DeFi, it contains an inherent risk of contagion as a networked money market fund. Contagion is when a financial default in an intermediary or asset triggers a cascade of failures. Although Compound only holds crypto assets, when analyzing Compound for contagion, [204] found that default cascades are more likely to stem from stablecoin pools, mainly due to their high utilization rates and the dependency on crypto assets as collateral for loans. As Compound plays an important role in the crypto lending markets, it is likely that the protocol will attract regulatory focus, yet not to the extent of MakerDAO, which poses a systemic risk with its stablecoin and a potentially high contagion effect due to the acceptance of real-world assets.

6.4 Summary findings from the evaluation

MakerDAO's broad objective function poses challenges for its organizational structure as a DAO and faces increasing regulatory scrutiny, particularly under MiCA, which takes effect at the end of June 2024 and mandates decentralization assessment. The path towards decentralization under MakerDAO's Endgame plan will likely be scrutinized, especially given its size, potential under-reservation, and contagion risk related to real-world asset collateral. However, MakerDAO's established presence in DeFi might find utility in less mature and regulated markets. Uniswap, although possibly operating as a fully decentralized exchange and adhering to its narrow objective function, does not officially identify as a DAO. Uniswap Labs' design reduces its role but retains significant influence through governance tokens, indicating insufficient decentralization and regulatory uncertainties regarding its classification. When MiCA comes into effect for CASPs, Uniswap Labs will likely need to obtain a license due to its control over a key access point to DeFi and the Protocol AMM, with investor concentration also likely being scrutinized, as discussed in [157]. Compound's objective function aligns with a DAO format, but its organizational decentralization has not progressed as anticipated. With substantial control retained by Compound

Labs and concerns over potential contagion risks from stablecoin pools, Compound remains significant in crypto lending markets and will likely attract regulatory attention.

7. Discussion

The initial phase of my Ph.D. research was driven by a wish to investigate the technical and organizational factors that influence DeFi applications on DLT/blockchain, the so-called web3-tooling of decentralized finance, and how to bridge this tooling to traditional finance.

The research program coincided with the preparation of regulation of crypto assets as regulated financial activity in the EU (MICA), and with my background in law and consulting with large banks on compliance matters; the dissertation took more of a direction towards the decentralization aspects of DeFi organizations – DAOs, their regulatory treatment and technically, the application of different types of DLT in regulated finance, and their regulatory treatment. This involved deriving fundamental properties of blockchain and characteristics of DAOs and the DeFi ecosystem from existing literature. Paper 1, 'When is a DAO Decentralized?' [47], explored the critical question of what constitutes sufficient decentralization in DAOs. Through thematic analysis and expert interviews, it provided a workable definition of sufficient decentralization and a framework with five dimensions for evaluating decentralization.

The publication of that first study coincided with regulatory enforcement actions from the US regulators against certain DAOs and smart contracts deployed on permissionless public blockchains to obfuscate the origins and destinations of stolen crypto assets, e.g., money laundering. Those events triggered the next paper, paper 2, 'How should DAOs be regulated?' [48] that offered a commentary on the regulatory challenges facing DAOs, illustrated by the Tornado Cash case. It discussed the implications of regulatory enforcement on the future of DAOs.

Meanwhile, the EU reached a regulatory agreement on the DLT pilot regime, a regulation supposed to enable DLT application in EU securities trading, clearing, and settlement. This led to a design research project in paper 3, 'Trading Green Bonds Using Distributed Ledger Technology' [49] that investigated the application of DLT in issuing, trading, and settling securities. This research highlighted the limitations of public permissionless blockchains for capital market operations due to finality requirements and, using a DSR approach, suggested a multi-sharded, permissioned network as a more suitable solution, offering a near-production level technology artifact.

In parallel, from an innovation perspective, the regulation was found unsuitable to support new market entrants as the central banks had not then implemented central bank digital currencies, and the regulators were unwilling to allow a new entrant an e-money license with an account in a central bank. Hence, new entrants would be obliged to settle the cash leg of securities trading via incumbents and traditional money, resulting in a lack of benefit realization overall.

Concurrently, we researched the potential for DLT in compliance reporting in paper 4, 'DLT for Compliance Reporting' [51] that examined the potential of DLT to optimize very expensive compliance reporting for banks in the EEA. It highlighted how DLT can automate compliance reporting, reduce costs, and enhance supervisory oversight through a 'pull model' that provides real-time access to compliance data, significantly optimizing financial institutions' processes.

With the increasing academic production around DAOs, paper 5, 'Do You Need a DAO?' [38] presented a gated decision-making framework to help organizations determine the suitability of a DAO for their needs. Based on a comprehensive literature review and thematic analysis, the framework identified practical challenges and gaps between DAOs' theoretical potential and their real-world applications, offering guidance for aspiring and existing DAO communities.

In parallel, generative AI was introduced to the public in late 2022 and has since taken the world by storm. This led to a research project looking into whether generative AI in open-access models could manage and moderate off-chain elements of decentralized communities, using the case of blockchain-based gaming, but generally applicable across decentralized and traditional organizations. Paper 6,

‘Scaling Culture in Blockchain-based Gaming’ [52] demonstrates how generative AI can support cultural production, automate internal controls, and reduce agency costs, thus enhancing the relevance of DAOs as organizational forms.

In this integrative chapter of the dissertation, we conclude the research in progress published in paper 5 with a separate research question focusing on DAO suitability in regulated finance: ‘Are DAOs and DeFi fit for regulated financial activity?’

This research explores the technical foundations of DAOs and blockchain and the strategic considerations for organizational design and regulatory responses. Assuming the community operating the DAO can manage smart contract governance efficiently and effectively, accept fluid, pseudonymous work practices, and embrace and sustain a culture based on token-based incentives, the framework suggests that the suitability of DAOs in regulated financial services is primarily a result of four competing forces: (i) The objective function of the service in question, (ii) the market maturity where the service is offered, (iii) the regulatory pressure in the same, and (iv) the level of decentralization of the DAO offering the service.

We can perhaps illustrate this in Figure 7.1, which shows the relevant space for DAOs in the total organizational space. In Figure 7.1, the regulatory compliance axis or dimension shows that a DAO as an organizational form increasingly struggles as compliance obligations or legal ambiguity increases. Still, it is possible to operate even in regulated markets if fully decentralized, which is illustrated by the DAO space turning yellow as compliance obligations increase.

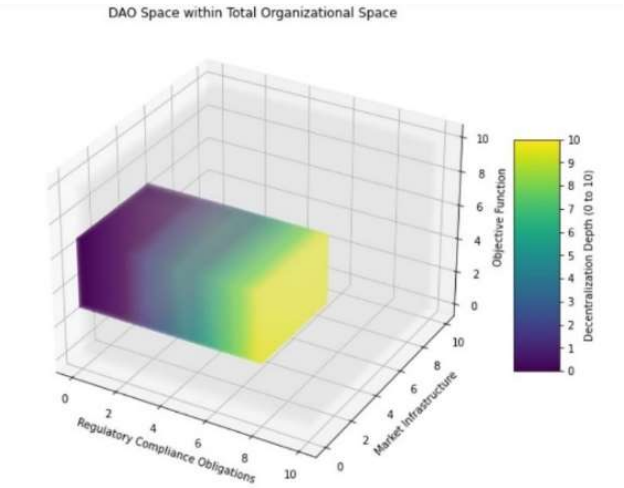

Figure 7.1. DAO space in the total organizational space.

Yet, it seems currently not possible for a DAO on a permissionless blockchain to operate critical financial (or other) infrastructure that requires high throughput, real-time finality or other critical elements, especially identified agency and accountability. This is mainly a result of DAOs operating on public permissionless blockchains with inherent drawbacks to those topics. As DLT evolves it should potentially be possible for DAOs to become relevant in that space as well, perhaps in a future ‘Finternet’ where financial services firms operate critical nodes in a multi-sharded ledger as we presented in paper 3 [49] in a decentralized fashion. The market infrastructure dimension illustrates that where DAOs may thrive in less mature markets, they increasingly struggle as markets mature, as the coordination cost to manage stakeholder expectations increases with centralized control preferences and low-risk appetite. In such markets, the permissionless public concepts struggle, whereas in less mature markets, they might excel. We have not investigated that aspect in this dissertation but hypothesize it is the case, using MiCA regulation as an example and evaluating three prominent DAOs on the same. Finally, the objective function illustrates that DAOs may not be suitable for narrow objective functions, as there is no organizational need, the technology to support it can be fully automated in line with the ‘governance minimization’ principle, nor is a DAO suitable for

very wide objective functions as coordination cost increase and make DAOs a less attractive organizational form compared to traditional, more centralized structures.

By analyzing various use cases and markets, the integrative chapter provides a taxonomy and framework to better inform users of DAOs and DeFi about these modern organizational forms and their suitability in regulated financial services, thereby contributing to the multidisciplinary DeFi and DAO discourse and practitioner agenda. The research also contributes to the IS discourse on organizational theory and practice by proposing two key dimensions where DAOs have unique attributes, further integrating decentralized governance models into established theoretical frameworks for organizational design. Further, by exemplifying, analyzing, and evaluating DeFi protocols with respect to all framework dimensions, the research identifies the three-tiered level of decentralization as the core for the evaluation of DeFi DAO decentralization level while also contributing with a framework to assess this three-tiered novel requirement.

The combined dissertation explores blockchain tooling from both decentralized and traditional finance perspectives, demonstrating that DLT can modernize traditional finance and capital markets due to its regulatory compatibility and operational benefits. However, permissionless DLT faces significant challenges in this context. The research shows that DAOs, primarily used in DeFi, offer minimal utility in the critical financial infrastructure of mature markets and limited utility in other mature financial systems unless they achieve genuine decentralization. Even then, DAOs must continuously comply with regulatory requirements and stakeholder expectations.

I will now discuss the results from the combined studies from a regulatory, theoretical, and practical perspective.

7.1 Regulatory perspective

The policy objectives in finance necessitate regulation and compliance, shaping the evolving regulatory and policy landscape for decentralized technologies regarding regulated financial services. This research contributes to this discourse by exploring the regulatory treatment of distributed and decentralized technology in financial instruments and the organization of decentralized finance. It also enhances the academic dialogue on fintech regulation, offering insights for policymakers on regulating emerging technologies to foster innovation while ensuring stability, transparency, and fairness.

Specifically, the research in paper 3 [49] contributes a novel approach to addressing the traditional financial market, exemplifying how DLT can drive environmental accountability and support the transition to Net Zero. Additionally, paper 4 [51] demonstrates the application of distributed ledger technology (DLT) in streamlining compliance reporting within the financial sector, providing practical insights into the convergence of technology and regulation and offering a model that enhances operational efficiency and regulatory adherence. Despite challenges in the DLT pilot regime (DLTR), the design artifact proposed in paper 3 [49] could also be effective in traditional finance. However, it would likely require different legal management to meet existing regulatory standards not designed for atomic settlement of delivery vs. payment. Combined, papers 3 [49] and 4 [51] illustrate the compatibility of DLT with traditional finance and capital markets. In contrast, the integrative chapter of the dissertation, together with papers 1 [47], 2 [48], and 5 [38], takes the decentralized perspective, contributing a framework for analyzing decentralized financial systems and organizations in regulated financial activities.

Paper 6 [52] expands the understanding of integrating generative AI in blockchain pseudonymous communities, demonstrating how blockchain and AI can redefine cultural production and digital engagement while serving as efficient internal control mechanisms in traditional and decentralized finance.

The integrative chapter contributes a comprehensive evaluation framework for DeFi DAO and DeFi protocol suitability, revealing that popular DeFi protocols often fall short of true decentralization. Issues include centralized governance structures, reliance on centralized infrastructure, and identifiable entities controlling key aspects of financial service provision.

While the three protocols evaluated under the framework are challenged in the decentralization test for different reasons, the three-dimensional decentralization concept has further practical and regulatory implications. If the assertion holds that the user interface (UI) for DeFi must also be decentralized, as determined by the Dutch court in the Tornado Cash case and suggested by MICA, this has significant regulatory implications. Specifically, regulators' supervisory scope would include non-financial firms offering wallet services, such as through mobile phones. The practical enforcement of this remains to be seen. However, as discussed in Paper 2 [48], the US OFAC's sanctioning of the Tornado Cash smart contracts had far-reaching impacts on service providers within the cryptocurrency sector. These providers are now required to screen wallets for sanctions, similar to the obligations that would be imposed on crypto asset service providers under EU regulations. A broad interpretation of these regulations would necessitate that service providers offering hosted and unhosted wallets enabling access to DeFi must be authorized under MICA. Conversely, a narrow interpretation would limit this requirement to hosted wallet providers only. The practical ramifications of a broad interpretation could potentially signal challenges ahead for DeFi as an emerging sector. We have yet to see the results in practice, as MICA only comes into effect in December 2024 as regards the crypto asset service provisions. The technical standards issued by EU regulatory bodies during the implementation phase have not provided any guidance yet. Still, the Danish national competent authority in late June 2024 released a guideline suggesting such a wide scenario [205]. In parallel, through a separate action aligning with the wider scenario, the US Securities and Exchange Commission (SEC) sued software firm Consensys for providing unregistered securities services by enabling users of its non-custodial, popular wallet Metamask access to staking services, a service that the SEC claims “engages in the unregistered offer and sale of securities by participating in the distribution of the staking programs and operates as an unregistered broker with respect to these transactions” [206]. This action is interesting given the US courts had dismissed a similar claim just 3 months earlier, where the SEC asserted that centralized crypto exchange Coinbase’s non-custodial wallet was an unregistered broker by making its wallet available to [207]. The question in the US appears more focused on whether a non-custodial wallet meets the definition of a broker or dealer or merely a robot executing customers’ own transactions, an argument dismissed in several other cases, not least the Tornado Cash precedent that focused more on the enablement service.

Without getting into a technical discussion on the legal definitions, at least for the EU market, the definitions in MICA are clearer, and the direction in the US is very similar but likely requires congressional vetting for the US courts to align on interpretations. Overall, however, the findings presented in this combined research suggest that DLT can greatly enhance transparency, reduce costs, and improve security in transactional and compliance processes within traditional finance. Permissioned DLT systems provide a controlled yet efficient approach to modernizing financial infrastructures. In contrast, permissionless public blockchains may face challenges with regulatory and operational compatibility in mature financial markets, technically in services requiring real-time finality and full accountability, and generally, if the decentralization test is not met in all three dimensions, including for un-hosted wallet services.

Tokens “automatically created as a reward for the maintenance of a distributed ledger or the validation of transactions in the context of a consensus mechanism” (MICA recital 26) are classified as utility tokens. As an ‘offering,’ these rewards are technically not DeFi from a regulatory perspective, excluding the native tokens of popular permissionless public blockchains, such as Ethereum and Bitcoin, from the token offering particulars of the regulation. However, any secondary trading of these tokens is covered by MICA as regulated crypto asset services and, in the US, similarly as money transmitter services. Building on [37][126] the primary space for DeFi and DeFi DAOs in the overall space of DLT in regulated finance might then be presented in Figure 7.2 below, where the DeFi DAO space and other DeFi spaces are marked in grey. The latter consists of fully automated smart contracts that do not require organizational support and extend into other DLTs, as one could imagine, financial services offered on non-blockchain permissionless public DLTs. This would qualify as DeFi and be forward-looking, not as DAO DeFi as these are defined, where DAOs operate primarily on public permissionless blockchain space. The dotted line for other DLTs suggests an expansion outside the permissionless public blockchain. It is irrelevant for DeFi as it would be private or permissioned DLT,

i.e., not decentralized finance. Finally, on the far-left side, blockchain protocol DAOs would be those offering the native utility tokens used to maintain a blockchain.

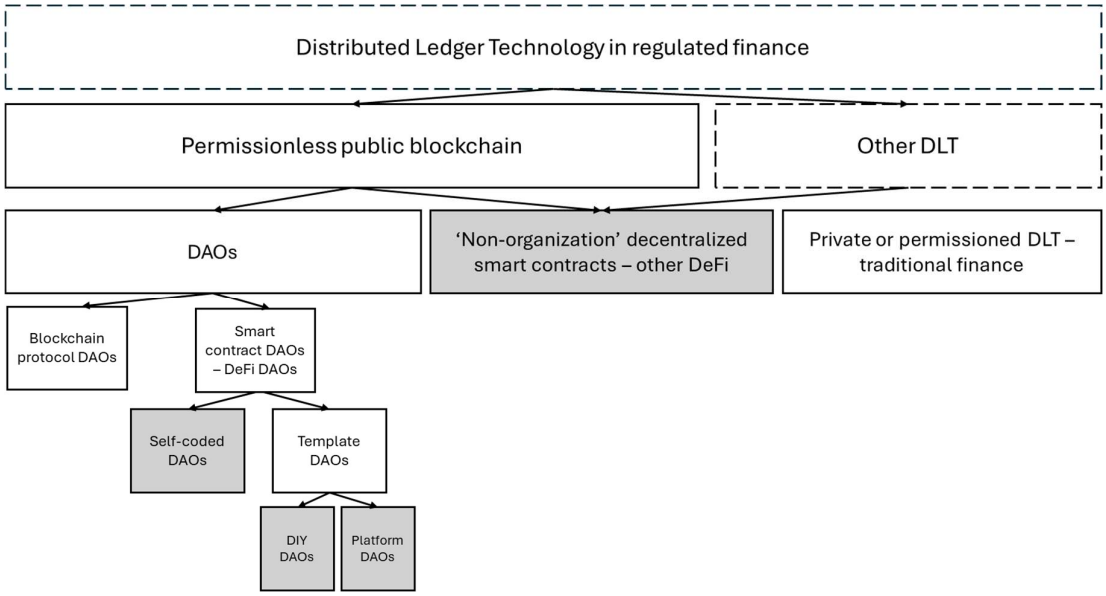

Figure 7.2. The space for DeFi DAOs in total DLT space.

Integrating DAOs and DLT into financial services represents an innovative shift towards more inclusive and efficient systems. However, significant challenges remain, particularly in regulatory compliance and achieving true decentralized autonomy. The divergence between theoretical aspirations and practical implementations of DAOs and DeFi indicates the need for continued refinement in technological and regulatory frameworks. Nevertheless, DAOs show potential in immature or volatile market environments with ineffective traditional structures. The findings may guide regulatory bodies in understanding the unique characteristics of DAOs and the necessity for tailored regulatory approaches that encourage innovation while ensuring compliance and consumer protection.

In evaluating the framework artifact regarding Uniswap v3, we mentioned that Uniswap technically appears decentralized concerning the business license handed over to the community. However, as Uniswap follows the same procedure as Compound regarding licensing and has already communicated an upcoming v4 launch later in 2024, this raises a question regarding point-in-time assessment vs. longer-term assessment. In paper 1 [47], we embraced the concept of gradual decentralization as proposed by a then-director of the US Securities and Exchange Commission in 2018 [208] We also mentioned that MICA does not embrace such an approach, as compliance, at least within the EU, is considered only at the time a regulated service is made available to the public, not on the basis of a future, potentially different, equilibrium state.

The notion that a protocol can oscillate between being decentralized and centralized depending on specific conditions or points in time poses a unique regulatory challenge, especially in the case of updates or new versions of protocols that may temporarily revert to more centralized control. The concept addressing this issue might be called 'functional equivalence,' where DAOs and DeFi protocols can be evaluated based on their functional outcomes in equilibrium state rather than their structural forms point-in-time.

This concept would allow regulators to apply existing regulatory frameworks to new technologies and business models by focusing on the functionality and risks they present in their equilibrium state with a functional assessment, where regulators look at what the technology does in its end state rather than how it is implemented, helping to determine if the core activities of a DAO or protocol align with regulated activities, acknowledging the temporal aspects, recognizing that the state of decentralization

can change over time. This concept prevents regulatory arbitrage, ensuring that entities cannot evade regulation simply by claiming decentralization, as regulators apply appropriate oversight based on functionality towards the equilibrium state. However, as mentioned, MICA does not acknowledge a grace period, creating yet another challenge for seemingly decentralized protocols that apply a copyrighted business license in their rollout of protocol improvements.

7.2 Theoretical perspective

This dissertation contributes to various theoretical perspectives that explore DAOs and DLT in financial systems. From the transaction cost economics viewpoint, it demonstrates how DAOs reduce transaction costs through transparent, automated governance and smart contracts, while also emphasizing the need for genuine decentralization and regulatory compliance for effectiveness in mature financial systems.

Institutional theory is used to discuss the regulatory shifts introduced by DAOs and presents a decision-making framework to assess their capabilities and structures. Agency theory is examined by designing a compliance artifact to reduce agency problems and exploring how generative AI can lower agency costs in cultural production and internal control.

The integrative chapter highlights the complex nature of decentralization in regulated financial services, focusing on principal-agent dynamics, reducing moral hazard, and ensuring accountability through decentralized mechanisms.

From a sociotechnical perspective, the research provides insights into how DAOs can integrate sociotechnical elements to meet regulatory needs. Additionally, it reflects on how DAOs promote new organizational designs and empower peer-to-peer communities.

This dissertation contributes to the understanding of decentralized governance models in DLT within regulated financial services. It proposes frameworks for assessing the suitability of DAOs for decentralized financial services and adds perspectives to the current IS discourse on how DAOs fit within organizational design theory. The research contributes to discussions on off-chain governance, showing that generative AI can significantly reduce agency costs, which may enhance the long-term viability of DAOs from a transaction cost perspective.

By critically examining the application and effectiveness of DAOs, the dissertation provides an analytical framework that complements the enthusiasm for decentralized governance models. It maps DAOs to organizational design theory and offers practical tools for assessing decentralized finance and DAOs providing regulated financial services.

Through the practical application of theory to the construction of design artifacts, the dissertation contributes to design science, especially in the context of blockchain and DLT, by working with practitioner researchers. This approach bridges the gap between abstract theoretical concepts and tangible technological solutions, introducing new insights into the IS discourse. The analysis of business models in digital finance also offers a potential taxonomy for decentralized finance.

7.3 Practical perspective

The empirical contributions of this dissertation are three-fold: (i) Practical insights and tools (papers 1 [47] and 4 [51]); (ii) technological innovations (paper 3 [49] and 6 [52]); and (iii) frameworks and taxonomies (paper 5 [38] and this integrative chapter).

The dissertation critically assesses DAO and DLT applications in regulated finance and capital markets, offering an analytical framework to evaluate DAOs and blockchain-based decentralized protocol effectiveness and appropriateness in regulated financial activities. This informs the evolving fintech landscape around DLT and how balancing innovation with stability, transparency, consumer protection, and fairness may be achieved through decentralized protocols while bridging abstract concepts with tangible solutions using various methods.

7.4 Combined perspectives

Overall, DeFi seems challenged in regulated financial activity in mature markets like the EU, with MICA coming into effect at the time of writing this dissertation, setting a very high bar for assessing decentralization and adopting the three-dimensional approach.DAOs are a very interesting phenomenon in this respect, but as the desktop evaluation of three prominent protocols revealed, decentralization through DAO structures is difficult to achieve, and the format is limited by the business objectives constraint.

Building on the timeline of DAO evolution in chapter 5.2 and looking ahead, the innovation focus in DeFi DAOs will likely be on advancements in governance algorithms, ethical considerations, and integration with AI and IoT technologies to automate operations, leading to a new era of DAOs that are more adaptable, ethical, and integrated into societal structures and finding a permanent fit in organizational theory and practice. In parallel, with the emergence of crypto regulations, there will likely be an increased scrutiny of DAOs' true level of decentralization and regulatory enforcement established when DAOs do not exhibit the core design elements but still claim to be treated as decentralized organizations.

Overall, the assessment framework confirms that DAOs should, by design, reduce transaction costs, align with emerging institutional norms, and embody collaborative principles. However, their ability to achieve these benefits depends on the strategic alignment of their governance structures and regulatory compliance obligations.

The contextual mappings presented in this dissertation provide a structured approach to understanding DAO characteristics within a comprehensive framework. Each dimension is positioned to articulate how internal features and external influences come together, forming a multi-dimensional analysis tool for evaluating DAOs against traditional and emerging organizational forms, but with a focus on financial services / DeFi. The framework is a foundational tool for further refinement and testing, guiding comprehensive evaluations of DAOs' suitability across different operational and strategic contexts.

We have outlined the complexities and challenges of using DAOs in financial services with a core focus on decentralization. However, DAOs that are not decentralized may offer a compelling alternative akin to cooperatives using permissionless public blockchain and token economics for global reach and markets where traditional organization forms cannot compete. In this context, it is worth remembering that more than 1 billion people in the world are still 'unbanked' [209], yet to a highly varying degree by market [210] but with a clear correlation to market maturity, i.e., emerging and immature markets having the lowest degree of financial inclusion. In this regard, DAOs or their incorporated counterpart, which we could call 'centralized autonomous organizations' and DeFi, may offer a compelling alternative to traditional financial organizations [211], also aligning with the Finternet aspiration from BIS mentioned earlier.

8. Conclusion

This dissertation demonstrates that distributed ledger technology (DLT) may play an important role in modernizing traditional finance and capital markets due to its regulatory compatibility and operational benefits. However, permissionless public blockchain, a subset of DLT, may face challenges in this context, at least in mature markets

The integrative chapter investigates the separate research question: 'Are DAOs and DeFi fit for regulated financial activity?' By focusing on DAOs as organizations in financial services, their primary application, and DeFi protocols more broadly, the integrative chapter seeks to enhance our understanding of DAOs and permissionless blockchain within regulated finance. Various theoretical perspectives, including organizational theory, transaction cost theory, agency theory, and sociotechnical theory, are used to assess DAOs and DLT/blockchain through the lens of technology-neutral regulation.

The research presented in paper 1 [47] was undertaken when the Markets in Crypto Asset regulation (MICA) was in draft, published in 2021. Recital 12 of MICA then opened for a broader interpretation of what might constitute 'sufficient decentralization': "This Regulation applies to natural and legal persons and the activities and services performed, provided or controlled in any manner, directly or indirectly, by them, including when part of such activity or services is performed in a decentralized way" [212].

The final MICA regulation, published two years later in 2023 added,"...Where crypto-asset services are provided in a fully decentralized manner without any intermediary, they should not fall within the scope of this Regulation" [19], but without providing any further clarity or regulatory technical standards for the interpretation of what 'fully decentralized' should mean or how it should be assessed.

Hence, research continued to focus on this question, including in this dissertation. The analytical core of the integrative chapter of this dissertation is an evaluation framework with eight criteria derived from academic papers, publications, and other literature. The principal issue arises from the practical application of decentralization, as demonstrated in evaluating three prominent DeFi protocols using the framework artifact. In contrast to the results in paper 1 [47], decentralization has since evolved into a broader and more transformational concept with three dimensions regarding financial services activity.

The analysis suggests that 'sufficient decentralization' has become a mirage, if it ever existed; 'fully decentralized' means 'complete decentralization' on all three dimensions – technically, organizationally, and in the manner the regulated service is made available to the public. This suggests complete decentralization on all three dimensions is the only viable option for DeFi in highly regulated markets such as the EU. Even then, they must continuously comply with regulatory requirements and stakeholder expectations or risk being shut down through enforcement actions enacted through the service providers. Additionally, DAOs encounter organizational design challenges to other structures when having overly broad or very narrow business objectives.

While we have yet to see whether MiCA and this high bar for decentralization will mean the end for DeFi and DAOs in DeFi in the EU, blockchain technology appears generally beneficial for scenarios involving untrusted parties. It eliminates the need for centralized control and enhances transparency, allowing participants to audit the network independently. This means access, where traditional organizational forms cannot compete, suggesting DeFi and DeFi DAOs may still have potential in underdeveloped or emerging economies with low levels of financial inclusion, where digital access via mobile phones can bridge financial gaps and traditional organizations, cannot reach end users efficiently.

9. Limitations and future work

This dissertation's research primarily focuses on DLT and DAOs in mature markets, particularly within the EU and its digital finance package, including DLTR and MiCA. Future research should explore the utility of DeFi and DAOs in less mature markets.

To our knowledge, the assessment framework is the first structured approach to evaluating DAOs' applicability to regulated financial services, fostering balanced discussions and highlighting the dynamic nature and potential of DLT. While initially tested on a few empirical examples, further evidence could stress test various DAO applications, contributing to the IS discourse on blockchain and DAOs. Also, the assessment framework introduced is an early attempt to evaluate DAO suitability in financial services. It should be seen as dynamic and non-exhaustive, designed to foster balanced discussions among researchers and practitioners, highlighting important research questions and relevant literature.

The integrative chapter suggests several future research avenues: (i) examining conditions necessary for the long-term survivability of DeFi and DAOs, including their potential for financial inclusion in emerging markets; (ii) exploring the concept of incorporated DAOs within the evolving regulatory

landscape, particularly under frameworks like MiCA, to enable innovation and accountability; (iii) investigating the broader socioeconomic impacts of blockchain and DLT on market communities and economies; (iv) addressing challenges of interoperability and scalability in DAOs across different blockchain systems; (v) studying the evolving regulatory landscape for decentralized technologies to adapt to unique challenges while maintaining ethical considerations; and (vi) conducting longitudinal studies on DAOs to understand their evolution and the practicalities of decentralized governance.

A current limitation of unregulated DeFi and DAOs is that they mainly serve self-referential financial ecosystems. Greater regulatory clarity could encourage traditional financial institutions to engage more proactively. Integrating traditional finance with DeFi could combine regulatory trust with technological potential, offering a path for web3 tools to disrupt traditional financial oligopolies if regulations adapt to support such innovation.

Practitioners suggest DAOs and other organizations in DeFi could operate under current regulatory ambiguity through cybernetic organizations in two forms: tech-enhanced companies with tokenized, programmable shares and trust-reduced entities like foundations with an emergency multi-signature (multisig) for DeFi protocols where a DAO controls the multi sig's powers. This could mainstream DAO benefits but may not solve governance design challenges or prove superior to cooperative models. The question is perhaps more of the traditional world to embrace this new technology than it is to insist on it mainly being relevant in pseudonymous, decentralized forms.

While mature markets require accountability in contractual relationships, and unincorporated DAOs expose personal liability to decision-makers, further investigation into regulatory compliance and legitimacy is needed. The EU is expected to report on DeFi regulation by the end of 2024, likely focusing on systemic risks and specific DeFi design risks, such as market failure related to self-referencing crypto assets, bridge constructs, incompatibility issues between different DLTs, and front-running, which is a feature of blockchain, but considered a bug in traditional finance.

Regulatory responses might include more lengthy technology-neutral documents or, as suggested by papers 3 [49] and 4 [51] and by the BIS in [17], technology-specific market infrastructure regulations and central bank digital currencies might be a better way forward. These could introduce a new level of precision in supervision, transparency in financial services, and dynamic compliance practices, challenging traditional, expensive control models like the '3-lines-of-defense' that were designed 30 years ago when the technology stack did not include immutable integrity ledgers. Such innovation could be more productive than creating complex new regulations in a field ripe for disruption.

Ultimately, DLT, DAOs, and DeFi have strong potential to deliver genuine decentralization and will likely continue to challenge the status quo.

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SECTION 2

Paper Overview

The papers are sorted by publication date.

Paper 1 *page 95-119*

When is a DAO Decentralized?

Henrik Axelsen, Johannes Rude Jensen, and Omri Ross

Abstract
While previously a nascent theoretical construct, decentralized autonomous organizations (DAO) have grown rapidly in recent years. DAOs typically emerge around the management of decentralized financial applications (DeFi) and thus benefit from the rapid growth of innovation in this sector. In response, global regulators increasingly voice the intent to regulate these activities. This may impose an excessive compliance burden on DAOs, unless they are deemed sufficiently decentralized to be regulated. Yet, decentralization is an abstract concept with scarce legal precedence. We investigate dimensions of decentralization through thematic analysis, combining extant literature with a series of expert interviews. We propose a definition of "sufficient decentralization" and present a general framework for the assessment of decentralization. We derive five dimensions for the assessment of decentralization in DAOs: Token-weighted voting, Infrastructure, Governance, Escalation and Reputation (TIGER). We present a discretionary sample application of the framework and five propositions on the future regulation and supervision of DAOs. We contribute new practical insights on the topic of compliance and decentralized organizations to the growing discourse on the application of blockchain technology in information systems (IS) and management disciplines.

This paper was first published in Complex Systems Informatics and Modeling Quarterly Journal Complex Systems Informatics and Modeling Quarterly (CSIMQ). eISSN: 2255-9922, Published online by RTU Press, https://csimq-journals.rtu.lv, Article 176, Issue 31, June/July 2022, Pages 51–75, https://doi.org/10.7250/csimq.2022-31.04.
A summary of the paper was published by Smart Contract Research Forum on https://www.smartcontractresearch.org/t/research-summary-when-is-a-dao-decentralized/1903.
A modified version of the paper was published after peer-review by Zeitschrift für das Recht der digitalen Wirtschaft (ZdiW), 2022, volume 10, page 386-390.
The paper will be republished in August 2024 as part of conference proceedings in DAO Lisbon Observatory Research project, University of Lisboa, Portugal: Decentralized Autonomous Organization (DAO) Regulation Principles and Perspectives for the Future. Edited by Madalena Perestrelo de Oliveira and António Garcia Rolo. DOI 10.1628/978-3-16-163701-8.
Preprints were posted on (i) https://www.researchgate.net/profile/Henrik-Bjorn-Axelsen/publication/362512779_When_is_a_DAO_Decentralized/links/6311c4cfacd814437ff8d017/When-is-a-DAO-Decentralized.pdf, (ii) on arXiv - https://arxiv.org/abs/2304.08160, https://doi.org/10.48550/arXiv.2304.08160 and (iii) on SSRN at https://papers.ssrn.com/sol3/papers.cfm?abstract_id=4210073.

Paper 2 *page 120-130*

How Should DAOs be Regulated? A New Perspective on Decentralization

Henrik Axelsen and Omri Ross

This paper was published in Amplify, volume 10, 2022/11, p8-17 at https://www.cutter.com/article/how-should-daos-be-regulated-new-perspective-decentralization

Paper 3 *page 131-146*

Trading Green Bonds with Distributed Ledger Technology

Henrik Axelsen, Ulrik Rasmussen, Johannes Rude Jensen, Omri Ross, Fritz Henglein.

Abstract
The promising markets for voluntary carbon credits are faced with crippling challenges to the certification of carbon sequestration and the lack of scalable market infrastructure in which companies and institutions can invest in carbon offsetting. This amounts to a funding problem for green transition projects, such as in the agricultural sector, since farmers need access to the liquidity needed to fund the transition to sustainable practices. We explore the feasibility of mitigating infrastructural challenges based on a DLT Trading and Settlement System for green bonds. The artefact employs a multi-sharded architecture in which the nodes retain carefully orchestrated responsibilities in the functioning of the network. We evaluate the artefact in a supranational context with an EU-based regulator as part of a regulatory sandbox program targeting the new EU DLT Pilot regime. By conducting design-driven research with stakeholders from industrial and governmental bodies, we contribute to the IS literature on the practical implications of DLT.

This paper has been published at the European Conference on Information Systems (ECIS) ECIS 2023 Research Papers. 340. https://aisel.aisnet.org/ecis2023_rp/340.
Pre-prints were posted on arXiv at https://doi.org/10.48550/arXiv.2304.08154 and SSRN on https://papers.ssrn.com/sol3/papers.cfm?abstract_id=4420803.

Paper 4 *page 147-158*

DLT Compliance reporting

Johannes Rude Jensen, Henrik Axelsen and Omri Ross

Abstract
Today, local financial institutions are responsible for submitting compliance reporting data to the supervisory authorities. This is commonly referred to as the 'push model'. The increasing complexity of reporting obligations often results in delayed reporting which delivers a fragmented and incomplete macroeconomic overview of the financial sector. Working with a group of nine representatives from industry and regulatory authorities, we employ the design science research methodology (DSR) in the design of an artefact, enabling the automated collection and enrichment of transactional data from DLT ledgers. Our findings demonstrate how the adoption of DLT in the financial sector will facilitate the automation of compliance reporting through a 'pull-model', in which regulators can access compliance data in near real-time and stage aggregate macroeconomic risk exposures for the eurozone. The findings contribute practical insights to the discourse on design-driven research on DLT and blockchain technology.

This paper was published in Complex Systems Informatics and Modeling Quarterly (CSIMQ) eISSN: 2255-9922, Published online by RTU Press, https://csimq-journals.rtu.lv
Article 195, Issue 35, June/July 2023, Pages 92–103, https://doi.org/10.7250/csimq.2023-35.04

Paper 5 *page 159-167*

Do You Need a DAO? A framework for assessing DAO suitability

Henrik Axelsen, Johannes Rude Jensen, Omri Ross

Abstract

Decentralized Autonomous Organizations (DAOs) have seen exponential growth and interest due to their potential to redefine organizational structure and governance. Despite this, there is a discrepancy between the ideals of autonomy and decentralization and the actual experiences of DAO stakeholders. The Information Systems (IS) literature has yet to fully explore whether DAOs are the optimal organizational choice. Addressing this gap, our research asks, "Is a DAO suitable for your organizational needs?" We derive a gated decision-making framework through a thematic review of the academic and grey literature on DAOs. Through five scenarios, the framework critically emphasizes the gaps between DAOs' theoretical capabilities and practical challenges. Our findings contribute to the IS discourse on blockchain technologies, with some ancillary contributions to the IS literature on organizational management and practitioner literature.

This paper was published in the European Conference on Information Systems (2024). ECIS 2024 Proceedings. https://aisel.aisnet.org/ecis2024/track16_fintech/track16_fintech/2.
A pre-print was posted on arXiv at https://doi.org/10.48550/arXiv.2404.11076 and https://papers.ssrn.com/sol3/papers.cfm?abstract_id=4796067.

Paper 6 *page 168-192*

Scaling Culture in Blockchain Gaming: Generative AI and Pseudonymous Engagement

Henrik Axelsen, Sebastian Axelsen, Valdemar Licht, Jason Potts.

Abstract
Managing rapidly growing decentralized gaming communities brings unique challenges at the nexus of cultural economics and technology. This paper introduces a streamlined analytical framework that utilizes Large Language Models (LLMs), in this instance open-access generative pre-trained transformer (GPT) models, offering an efficient solution with deeper insights into community dynamics. The framework aids moderators in identifying pseudonymous actor intent, moderating toxic behavior, rewarding desired actions to avoid unintended consequences of blockchain-based gaming, and gauging community sentiment as communities venture into metaverse platforms and plan for hypergrowth. This framework strengthens community controls, eases onboarding, and promotes a common moral mission across communities while reducing agency costs by 95 pct. Highlighting the transformative role of generative AI, the paper emphasizes its potential to redefine the cost of cultural production. It showcases the utility of GPTs in digital community management, expanding their implications in cultural economics and transmedia storytelling.

This paper is currently in review, preprint posted at arXiv:2312.07693, 2023.
An earlier research-in-progress pre-print was posted on arXiv with a different title – ‘Can AI moderate online communities’ and co-authors Johannes Rude Jensen and Omri Ross at https://doi.org/10.48550/arXiv.2306.05122.

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When is a DAO Decentralized?

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Abstract. While previously a nascent theoretical construct, decentralized autonomous organizations (DAO) have grown rapidly in recent years. DAOs typically emerge around the management of decentralized financial applications (DeFi) and thus benefit from the rapid growth of innovation in this sector. In response, global regulators increasingly voice the intent to regulate these activities. This may impose an excessive compliance burden on DAOs, unless they are deemed sufficiently decentralized to be regulated. Yet, decentralization is an abstract concept with scarce legal precedence. We investigate dimensions of decentralization through thematic analysis, combining extant literature with a series of expert interviews. We propose a definition of "sufficient decentralization" and present a general framework for the assessment of decentralization. We derive five dimensions for the assessment of decentralization in DAOs: Token-weighted voting, Infrastructure, Governance, Escalation and Reputation (TIGER). We present a discretionary sample application of the framework and five propositions on the future regulation and supervision of DAOs. We contribute new practical insights on the topic of compliance and decentralized organizations to the growing discourse on the application of blockchain technology in information systems (IS) and management disciplines.
Keywords: DAO, Sufficient Decentralization, Regulation, DLT, Blockchain, Compliance.

1 Introduction

In financial markets, regulatory objectives traditionally focus on (1) proper functioning and integrity of markets, (2) financial stability, (3) protecting the collective interests of consumers and investor protection, while also (4) aiming to reduce criminal activity and (5) preserving monetary sovereignty.

The crypto economy has experienced rapid growth in recent years, amounting to USD 3 Trillion in late 2021 [1]. Due to its open-source nature, the sector is subject to high competition and enables

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decentralized finance (DeFi). DeFi replicates traditional financial services; hence the industry is becoming increasingly important to regulators [2], [3].

The crypto economy operates on permissionless blockchain technology. Regulators see this technology as imperative to innovation, growth, and global competitiveness. While crypto remains primarily unregulated, regulators across the globe are motivating and implementing crypto regulation to meet the challenge of ensuring consumer protection, innovation, and growth without stifling innovation [4], [5].

In recent years, scholars from a wide variety of disciplines have found a shared interest in examining the implications of the technical properties of blockchain technology in their fields. Concepts such as the self-enforcement and formalization of rules, automatization, decentralization of authority, transparent execution of business processes, and codification of trust appear to be conducive to wide-ranging theoretical and industrial innovation.

While there are multiple working definitions of the concept of decentralized autonomous organization (DAO) in industry, most take the form of fluid organizations or loosely organized communities, self-directed and governed through smart contracts without the presence of central authority or a managerial hierarchy [6], [7].

DAO tends to operate through bottom-up interaction and coordination among a set of independent and distributed rational agents. This has increased interest in how DAOs can mitigate principal-agent problems and reduce misconduct by improving [8] through shifting power dynamics. Some observers compare DAOs to nation-states rather than traditional organizations [9]. In this analogy, the formal (on-chain) smart contracts are comparable to a "computational constitution." At the same time, cultures are nurtured through communication emerging around the design, development, and maintenance of the products governed by the DAO.

While Ethereum remains the dominating network, DAOs are now proliferating across blockchains, facilitated by innovation in the underlying infrastructure. There are currently some 5 000 individual DAOs, counting more than 1.7m token holders, and some 700 000 active voting members [10].

Implementing regulatory objectives imposes a high compliance burden for industry participants [14] in traditional finance. For European actors, the total cost of compliance ranges between 2 and 25% of total operating expenses, depending on the size and complexity of the institution [11], [12]. Being subjected to traditional financial institutions' comparatively strict compliance requirements may prove challenging, if not impossible, for DAOs as they are designed today. Regulatory compliance imposes capital and liquidity requirements, strong centralized controls and separation of functions, management hierarchies, and complicated reporting.

Hence, if existing regulation is applied without scrutiny, the novel and poorly defined concept of a DAO may give rise to both conventional and emerging regulatory risks. A key driver among these risks is the prevailing ideological assumption that for regulation to have an effect, a subject in the form of a legal or physical person is required to be held accountable for obligations arising from DAO activities, including those related to regulated financial activities.

Recently, global regulators indicated that the issuance of crypto assets, which may otherwise be subject to compliance requirements, may be exempt if distributed by an entity predominantly or exclusively operating as a "decentralized entity" [5], [13].

Yet, none of the proposals published to date offer a working definition of what might constitute "sufficient decentralization."

As follows, designing a decentralized crypto-based business model based on "smart contracts" is complicated: In addition to the usual challenges in finding product market fit, product leadership, sales, recruitment, development, and scaling, founders must seek to operate their projected business in a decentralized manner or risk negative regulatory implications [14].

While founders may opt for the "Nakamoto model" [15] and operate in full anonymity, secondary service providers required to fund and execute a project are also subject to regulation. Consequently, fully anonymous (anon) stakeholders may find themselves operating in a vacuum, with limited access to ancillary services.

This article asks the following research question: *"When is a DAO (sufficiently) decentralized?"* We present an artifact designed to assess the level of decentralization in any given DAO across several dimensions. We seek to contribute new practical and actionable insights on the topic of decentralized organizations to the growing distributed ledger technology (DLT) discourse in the information systems and management disciplines. Further, we contribute to the growing regulatory discourse in crypto assets and decentralized finance by providing a pragmatic assessment tool for regulatory compliance assessment.

2 Background

2.1 Blockchain Technology and "Decentralized Autonomous Organizations"

Blockchain is a subset of DLT where transactions are recorded through immutable cryptographic signatures. A blockchain's primary function is maintaining an append-only ledger in a peer-to-peer network [16], using a consensus mechanism to validate transactions. Permissionless blockchains are decentralized computer networks that maintain a single global version of a shared database and a shared account ledger that is visible to all stakeholders [17]. Permissionless blockchains are open, so anyone can join, leave, read, and write as they please. No central party authorizes access, and its cryptographic primitives ensure collusion resistance [18]. Bitcoin [15] and Ethereum [19] are important instances of permissionless blockchains.

DeFi apps are financial solutions built with "smart contracts" operating through permissionless blockchain technology.

Smart contracts are scripts that automatically carry out specific business logic. Financial services or products created as smart contracts work autonomously without the need for monitoring or intervention from the software developers who originally designed the application due to the deterministic characteristics of the underlying blockchain.

This means that, as long as the blockchain is active, a smart contract will execute business logic unconditionally and irreversibly [20]. Typically, a smart contract will carry out a set of instructions that allow participants to lend or swap an underlying base asset or other financial assets that have been "tokenized" [21]. DAOs utilize these properties to create rules-based organizations, in which they make decisions instituted in code. A DAO will typically consist of multiple interacting smart contracts responsible for different parts of the DAO, including treasury management, the tallying of votes, and the token itself. All these smart contracts are deployed on the blockchain and maintained as stateful applications. Both users and smart contracts are represented by addresses and compute transactions in the database containing instructions on how to change the state. Transactions emitted to the network are then sequenced in blocks and circulated with the network, at which point a global state-change is enacted.

To illustrate the above, in Figure 1 we present a layered taxonomy in which the *protocol layer* represents the consensus model determining the logic by which blocks are generated and distributed; the *application layer* represents the virtual machine in which smart contracts are deployed, and the *interface* and *user* layers represent the web-based interface through which users can create and sign transactions.

When a user participates in DAO voting, this process is carried out through one or more transactions in which the user (1) maintains a balance of governance tokens on an address to which they control the private keys and (2) connects their wallet to sign a message or a transaction, enabling them to signal their approval or dismissal of a governance proposal.

While there are multiple ways to implement this logic, the leading solutions rely either on the collection of off-chain signatures through a voting interface (User A) or the direct collection of votes and implementation of pre-deployed code changes by the DAO contract (User B).

In response to voter apathy, DAOs may implement the option for vote-delegation. This is typically carried out directly in the token contract and implemented as a feature in which a token

holder can assign the voting power associated with their balance to a third-party address without losing custody of the tokens.

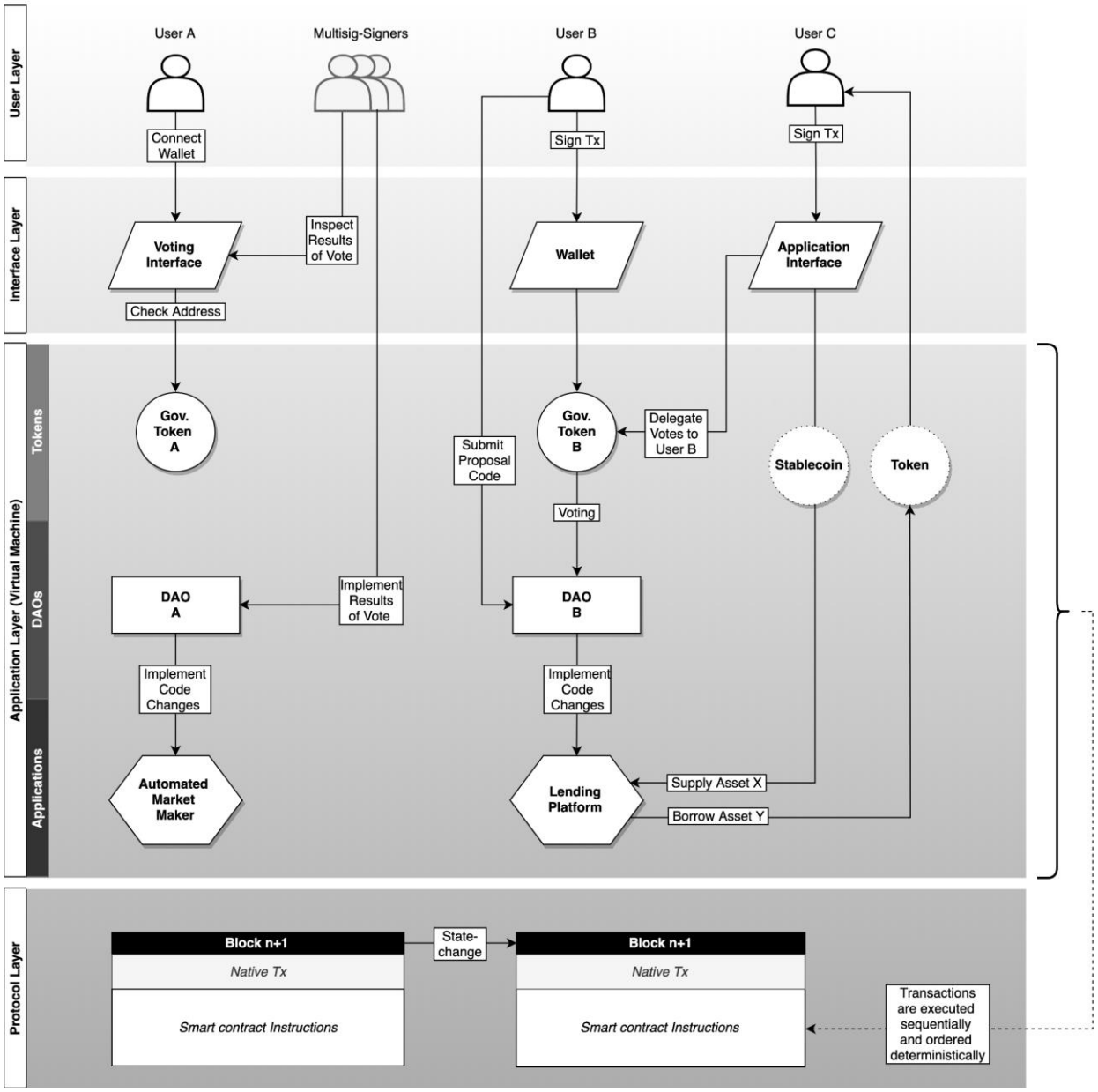

Figure 1. Blockchain, application layer, and users

2.2 The Problem of Defining Decentralization within a Regulatory Context

DAOs are mostly designed and instantiated by a small group of individuals who distribute power and control governance, with a promise to decentralize the governance process at some defined later stage [22].

Without legal recognition, most jurisdictions today may simply treat unregistered DAOs as unincorporated general partnerships, resulting in community members having personal, joint, and several liability for debts or legal actions arising from operating the DAO.

Increasingly, therefore, DAOs establish themselves with “legal wrappers” to protect DAO participants from unlimited liability, optimize tax treatment or engage in contractual “off-chain” transactions, even if not focused on regulatory compliance expectations and “sufficient decentralization” [23].

Because the common instantiation method is centralized from a design perspective, such a "wrapper" constitutes incorporation. It relates only to the autonomy and legal capacity of the organization, which technically does not prevent the concept of decentralization. Yet, DAOs that operate using a governance token, issued with a "*reasonable expectation of profits to be derived from the entrepreneurial efforts of others,"* are likely to be considered to undertake regulated financial activity [13].

Some scholars propose that a DAO, like autonomy classification for land and maritime environments [24], be considered autonomous to the extent that it can legally accept liability [22]. In practice, the level of autonomy and anonymity can vary, but a DAO is normally self-directed through voting on- and off-chain; it can be financial or non-financial in purpose, but the traditional legal system seems secondary to its existence and purpose [25].

In 2018, a US Securities and Exchange Commission (SEC) representative suggested that contractual and technical ways exist to structure digital assets, so they function more like consumer items or community enablers and less as regulated securities. At the same time, it was suggested that a security could become "sufficiently decentralized" over time so that it no longer is a security token under the so-called Howey test [13]. Since then, likely accelerated by the increasing success of DeFi, regulators across the globe have increasingly looked to regulate DeFi and DAOs, and uncertainty has prevailed.

Efforts to regulate DAOs as limited liability companies have emerged [26], [27]. More recently, progressive senators in the US are working on regional regulation of DAOs, yet this is still early draft, subject to extensive negotiations of political views [4].

As the first major region attempting to regulate crypto assets at the supranational level, the EU bloc emerged in 2020 with a digital finance package. The EU draft regulation included DAOs in the negotiation phase [5] with legal identity and limited liability for the community members. However, it was omitted in the final version of the regulation, called the Markets in Crypto Asset (MiCA) regulation, approved on June 30, 2022.

Much remains to clarify how DAOs will eventually become regulated, likely through a global policy setter, given the nature of DLT and the world-wide-web. At the time of writing, the final MiCA text is not published. Still, based on the EU Council's negotiation mandate, the regulation appears to treat decentralized activity in a manner similar to the US: "*This regulation applies to natural and legal persons and the activities and services performed, provided or controlled in any manner, directly or indirectly, by them, including when part of such activity or services is performed in a decentralized way…Where crypto assets have no offer or and are not traded in a trading platform which is considered to be operated by a service provider, the provisions of (this regulation, ed.) do not apply*" [28] (recital 12a).

This EU regulation appears to align with the global trend that certain crypto assets may become exempt from specific compliance requirements, even if constituting an activity that might otherwise be a regulated financial activity. But the question of the extent of decentralization required remains to be solved. As there is no definition of "sufficiently decentralized" proposed, nor is there, like in the US, any proposal of allowing a grace period for DAOs to mature to any given level of "sufficient decentralization" [29], such will likely have to evolve through regulatory technical standards set by the EU financial regulators. Combined, the typology suggests overlapping assumptions open for problematization [30].

This is further exacerbated by DAOs frequently operating across multiple jurisdictions with different views on decentralization, resulting in the matter becoming a topic of strategic importance as the uncertainty blocks investments, which impacts the competing growth and innovation objectives mentioned earlier.

2.3 Arriving at a Working Definition for Decentralization

The notion of "decentralization" has its origins in political science and, in the present time, generally refers to the dispersion or distribution of functions and powers. Without an

understanding of the powers of different stakeholders, where and how they exercise their powers, and to whom and how they are accountable, it is difficult to understand whether decentralization is taking place [31].

The concept of decentralization has been applied mainly within the government of nation-states and political science [32], administration [33], fiscal area [34], and environment [35], but also across a diverse range of disciplines, such as complex systems engineering [36], space safety engineering [37], cybernetics [38], management science [39], economics around principal agents theory [40], finance [15], law and technology [41], crypto-economic systems [9] and more.

Within the nascent literature on crypto, the most applied definition of decentralization was proposed by Ethereum co-founder Vitalik Buterin with the introduction of the term "DAO" in 2013 [25].

Here, decentralization is presented as a response to the latent issues of centralized systems, to which decentralized systems can introduce fault tolerance and deter attacks or collusion. In a later publication [42], Buterin suggested that decentralization be viewed across several dimensions: (1) An architectural dimension as in how many computers the system is made up of; (2) a political dimension as in how many controls those computers; and (3) a logical dimension as in how the interface and data structures add up.

Some scholars and practitioners suggest that decentralization is a misleading term, as it has a slightly negative connotation, and no large-scale social, economic or political institution can be fully decentralized and automated without human intervention. Decentralization is then considered more specific to an activity, not to an organization design dimension; instead, we might consider using collaborative models [43].

It follows that measuring decentralization is complicated; "*A true assessment of the degree of decentralization in (a country) can be made only if a comprehensive approach is adopted, and rather than trying to simplify the syndrome of characteristics into the single dimension of autonomy, interrelationships of various dimensions of decentralization are taken into account*" [44], [45].

We propose that "sufficient decentralization" is defined as a verifiable state, where (1) the design of the DAO is collusion resistant and based on long-term equilibrium; (2) its governance processes have unrestricted and transparent access.

3 Methodology

This article follows an inductive approach to framework development [46]. We chose thematic analysis as a method to reflect and unravel the surface of the "reality" of DAO decentralization [47] through interviews and literature review. We analyzed the data in six phases: (1) familiarize yourself with the data, (2) generate initial codes, (3) search for themes, (4) review themes, (5) define and name themes, and (6) produce the report.

We chose an explorative, qualitative research approach to identify the relevant dimensions of decentralization in a DAO. We conducted semi-structured, open-ended expert interviews to identify possible themes to supplement literature review findings.

Potential interviewees were approached through contacts from ongoing token engineering projects. We conducted eight interviews with experienced DAO experts and stakeholders (Table 1), each lasting 45–60 minutes.

At the beginning of each interview, we ensured proper consent and confidentiality. We used an interview guide [48] with 10 open questions probing the interviewees' perspectives on aspects of the structural elements of a DAO (decentralized, autonomous, organization) and additional dimensions for assessing decentralization specifically. Interviews were recorded and transcribed, amounting to 82 pages of transcripts and notes.

Table 1. Overview of Interviewees

DAO Expert	Expert role	DAO experience
E1	Complex Systems Architect and Designer	6 years
E2	Cryptoeconomist, token engineer, ecosystem designer	4 years
E3	Engineer, Data Scientist, DAO advisor	5 years
E4	Founder, DAO ecosystem tooling	4 years
E5	Serial entrepreneur, Co-founder misc DAOs	8 years
E6	Lawyer, Specialist in DLT/Blockchain projects	5 years
E7	Lawyer, Crypto Asset Specialist / DeFi legal expert	5 years
E8	Lawyer, DeFi specialist, National regulatory body	5 years

Although mainly conducted through one-to-one interviews in search of the "decentralization surface" of DAOs and with unclear requirements from the outset, our search process matches elements of a design science research (DSR) method [54], where the artifact design process informed an iterative process with stakeholders, leading to the final result. Our approach is summarized in Figure 2:

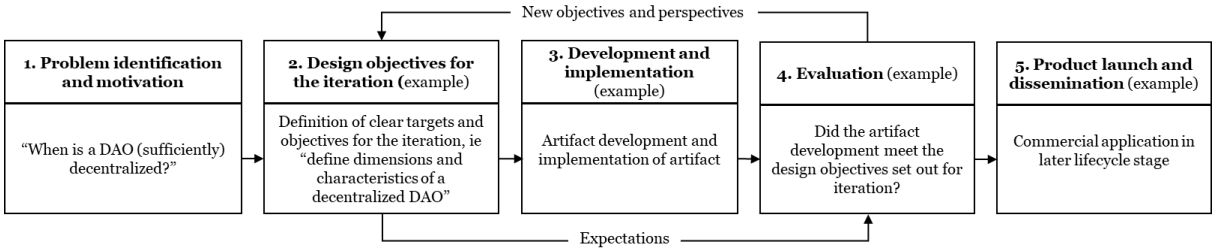

Figure 2. Our search process outline

After (1) reviewing transcripts and notes from interviews, we (2) extracted dimensions of decentralization and aligned them to the literature on DAOs and DeFi manually. The unit of analysis was the practices conducted by DAO communities, the subsystems used to perform these, and the technical infrastructure supporting them. All three authors were involved in the data analysis. As two authors were involved in the data collection, the third author maintained distance and acted as a devil's advocate to ensure the analysis remained objective and independent of our preconceptions and the interviewees' views [49].

As each expert had their own practical experience from working with DAOs, we first conducted a within-case analysis to gain familiarity with the data and generate a preliminary theory; then, we examined the data for cross-case patterns [50]. The coding procedure comprised several rounds of analysis and refinements of the codes. The topic of decentralization is multi-dimensional and complicated, having to determine the primary angle of analysis either by business subsystem, policy, or technical architectural dimension. During this procedure, we gradually moved from an inductive to an abductive approach [49], using labels to categorize the interviewee-specific language and grouping similar ones.

Our data sampling strategy remained open to new theoretical insights on what constitutes decentralization [51]. In (3) the search for themes, we clustered initial 52 first-order concepts across 7 DAO subsystems, 4 policy dimensions, and 4 technical architectural layers, further (4)(5) synthesizing these into 15 second-order themes across 5 aggregate dimensions. As we analyzed

the data and generated theoretical concepts, we cross-referenced our findings with the extant literature in an iterative process to align our findings.

Our literature review followed a "light approach" [48], where we developed the research protocol, defined – and refined – the research question, and added criteria for DAO research while focusing mainly on decentralization and acknowledging related characteristics to autonomy and organization. The DAO subsystems were identified using a DAO reference model [52]. Still, as the framework should satisfy regulatory and supervisory expectations of a risk-based approach, we also investigated a technical reference model proposed by regulators [53].

Once we had derived the first-order concepts, second-order themes, and aggregate dimensions, we built the data structure as appears in Figures 3a and 3b below.

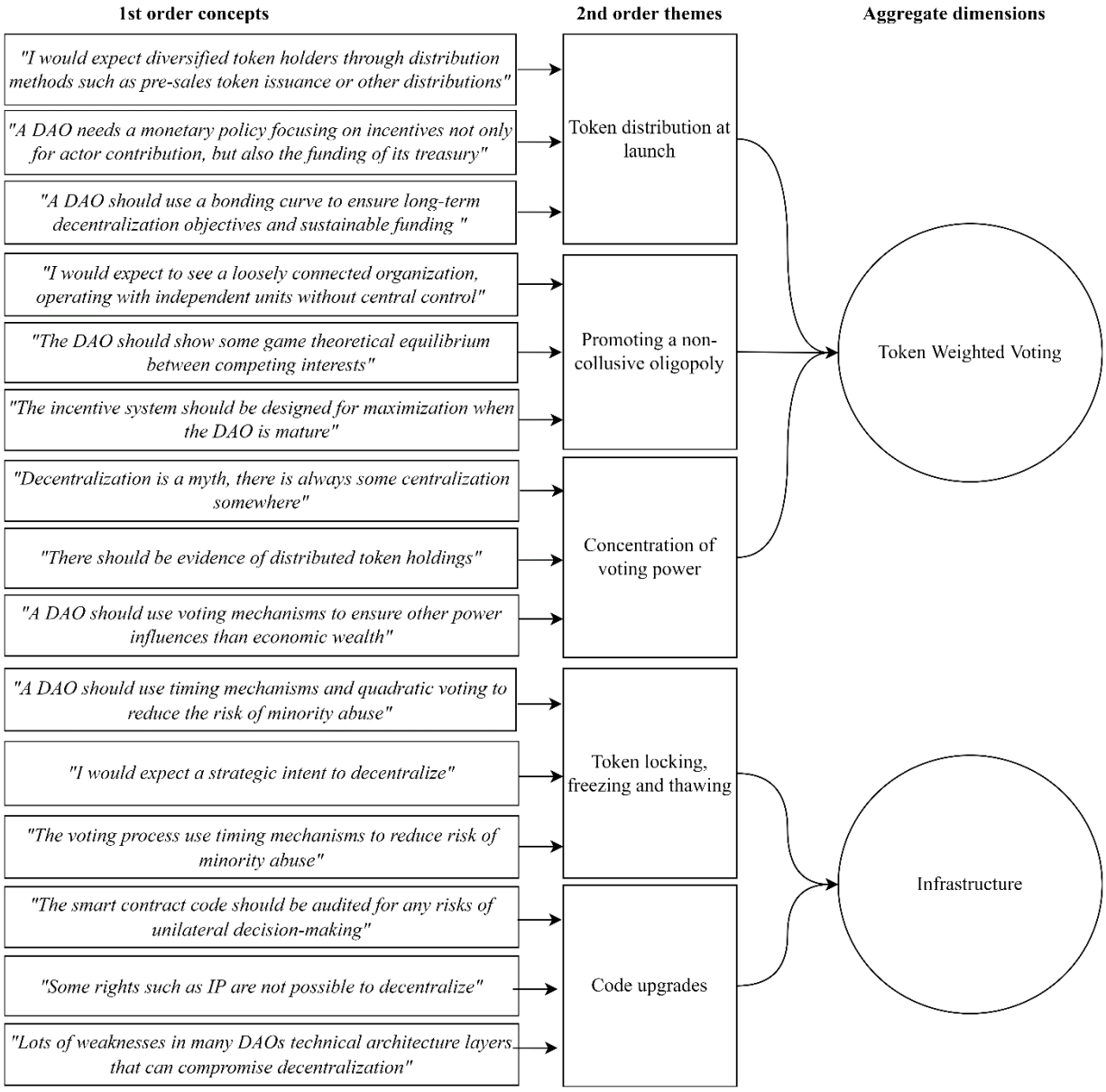

Figure 3a. Coding of data to themes (1 of 2)

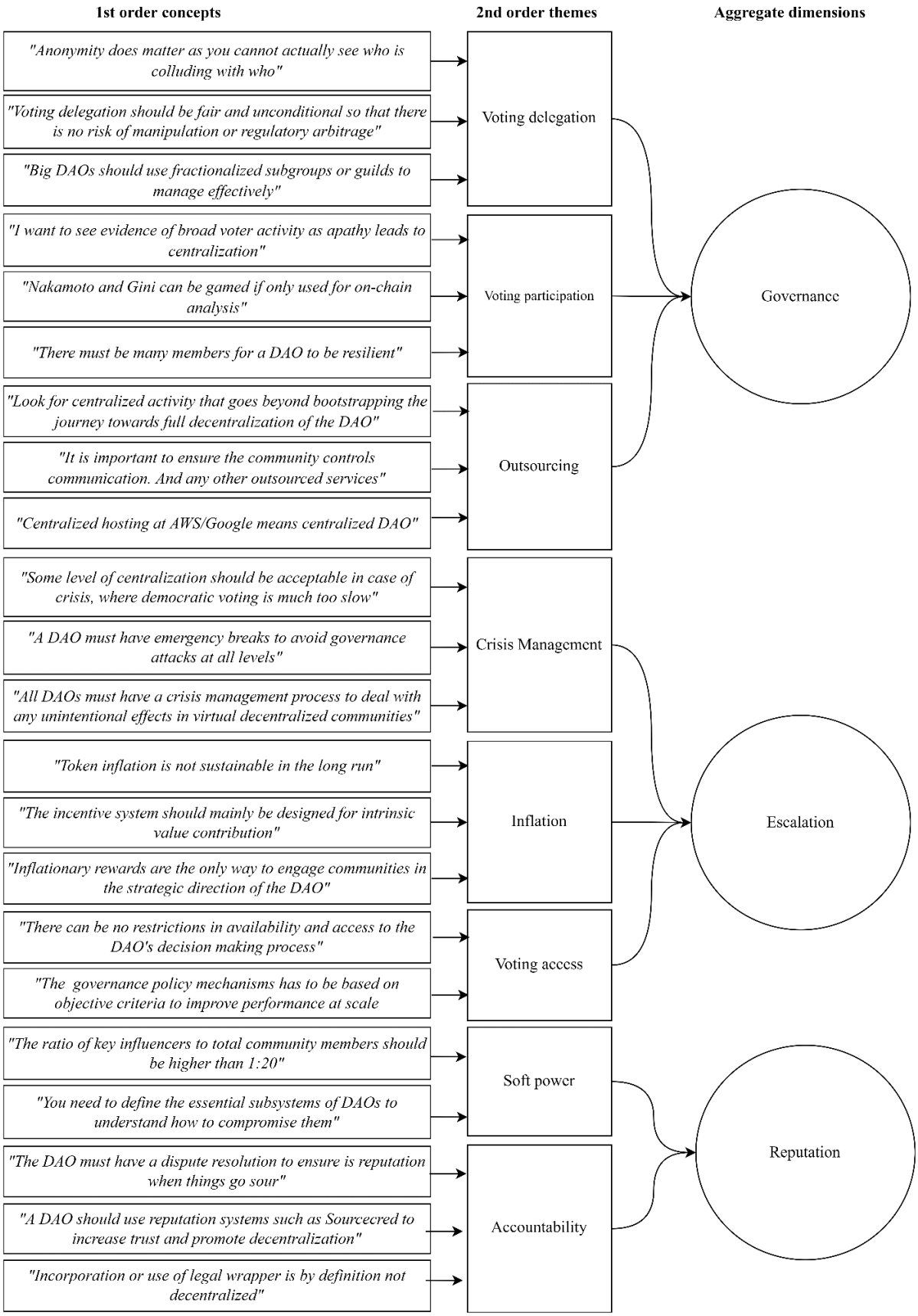

Figure 3b. Coding of data to themes (2 of 2)

The artifact was evaluated ex-ante by a representative from a regulator to ensure a level of alignment to regulatory expectations of the framework artifact.

4 Introducing "TIGER" Assessment Framework

The proposed artifact comprises a generalized DAO score-card evaluation framework. The framework facilitates a directional analysis of critical DAO components from a systems perspective, where compromising one subsystem may compromise the entire system [9], [43].

In the output component, we leverage traditional supervisory methods [55] and aim to score and consolidate each characteristic to generate an assessment score for each critical dimension that may affect the entire DAO level of decentralization if compromised. The central assessment approach is to which extent, on each dimension and its characteristics, we observe evidence of independent groups of agents operating under mandates without any centralized element of control.

The assessment is designed for point-in-time. Thus, no "safe harbor" assessment component is included, which could be relevant depending on the specifics of the DAO in question. We have, however, aimed to integrate strategic intent to allow a "grace period" to impact the scores. The actual application of scores requires some calibration and further consultations across DAOs and jurisdictions to evolve into a regulatory technical standard.

4.1 A Taxonomy of Agents in a DAO

Permissionless blockchains are essentially a vast network of databases maintaining a shared space. Transactions are batched and circulated with the network in the form of blocks which, once accepted by the network, amend the database with the most recent balance assigned to the known addresses. Maintaining a distributed database of transactions in this fashion introduces a high level of integrity. Still, it necessitates the encryption of user identities, as anyone with access to the database would otherwise be able to view the accounts balances of the individuals using the network.

Permissionless blockchains solve this issue with *private-key infrastructure* (PKI), in which a private/public key pair is used to generate any number of addresses. Traditional PKI is pseudonymous, as the user's identity is encrypted, but still predisposed to simple heuristic address clustering of transaction patterns [52]. As such, blockchain technology presents a fascinating paradox: Pseudonymous identities are essential in protecting user privacy but, at the same time, offer a design challenge for DAOs. Yet, the replicated nature of the database means that pseudonymous transaction data is available perpetually, enabling stakeholders to access the full transaction history for an address. Different agent definitions are shown in Table 2.

Table 2. Agent definitions

Agent type	Description	Sample of Evidence
Verifiably Independent Agent (VIA)	A publicly identifiable token holder (maybe with a sizeable reputational interest in maintaining the integrity of their address) with a long and repeated history of participation in governance and a public presence in the associated communities.	Proof of (real or pseudonymous) identification measures across multiple governance discussions and social media sites, a discernible asset trail, and/or identification standard tokens (Ethereum naming service)
Presumably Independent Agent (PIA)	A token holder with a presumed vested interest in a sound governance process and	An address with a transaction history indicating repeated and non-automated use on a near daily basis, coupled with interactions in other DAOs and a discernible transaction pattern.
Unidentifiable Agent (UIA)	All addresses not operated by a PIA or a VIA.	Addresses with indications of automation and repetitive transaction patterns or clusters.

4.2 The TIGER Assessment Questionnaire

After several iterations and pattern analysis, the conceptual artifact was optimized and consolidated to contain 15 characteristics with suggested questions and quantifiers for assessment as shown in Table 3. We summarize the requirements [56] in five general categories of DAO subsystems (items with grey background in column 1 of Table 3) based on expert input and literature [52]: Token Weighted Voting; Infrastructure; Governance, Escalation, and Reputation ("TIGER").

Table 3. TIGER Assessment Questionnaire

Topical Analysis	**Variables**	
Category	Question	Quantifier
Token Weighted Voting and Incentives		
Token distribution at launch	Did the team conduct a "fair" token launch designed to balance incentives for further decentralization with requirements for long-term funding and investor returns?	Percentage of units allocated to addresses associated with insiders, including core-team members, advisors, investors, early collaborators, and service providers.
Promoting a non-collusive oligopoly	Does the DAO algorithmically incentivize multilateral participation by rewarding non-colluding groups of agents for strategic participation?	Percentage of units allocated to clearly differentiated stakeholder groups indicated by a misalignment in assumed preferences
Concentration of voting power	How distributed are governance tokens amongst active/passive stakeholders?	Number of VIAs required to mount >51% of voting power in majority voting schemes?
Infrastructure		
Token locking, freezing, and thawing.	Does the token contract code include the ability for any set of stakeholders to lock, move, freeze, and thaw token balances on some or all addresses?	Number of VIAs required to freeze token balances in all or some addresses.
Code upgrades	Is there evidence of the possibility of enforcing unilateral decision-making in the code that may compromise decentralization? While most code upgrades will preserve address, state, and balance, any ability to change smart contract code will impose significant security risks to the DAO and its stakeholders.	The number of agents of any type required to effectively implement a proposal or other non-specified changes to the smart contract code. Code changes or upgrades may be implemented either following official voting sessions or unilaterally.
Access	To what extent is access to decision-making through voting or other means accessible to external parties or contributors in a meaningful and unrestricted way?	Mixed assessment relating to quorum and timing: (1) How many verifiably independent agents does it take to produce a positive voting outcome for a "general" Improvement Proposal (Nakamoto co-efficient for governance), and (2) Does the voting process allow proper time and access for token holders to vote on any topic?

Table 3. Continued

Topical Analysis		**Variables**
Category	Question	Quantifier
Governance		
Voting delegation	Is any voting delegation fair and unconditional so there is no risk of manipulating reported delegation?	How many VIAs with clearly distinctive preference profiles are presently available for delegation
Voting participation	Is there evidence of broad voter activity?	Percentage of token float with active participation in governance
Bootstrapping	Is there any centralized activity that goes beyond bootstrapping the journey toward full decentralization of the DAO?	*Qualitative assessment*: Is there evidence of centralized control measures that are not required for the long-term health of a decentralized DAO?
Escalation		
Crisis management	Does the constitution or policies include crisis management and dispute resolution mechanisms?	Percentage of tokens required to enact crisis management decision-making
Inflation	What is the distribution between token inflation accruing to user A. External (oligopolistic) incentives for non-colluding VIAs (LPs, open-source developers, etc.) and user B. Insider VIAs such as investors, founders, early stakeholders, etc.?	The percentage split user A/ user B.
Voting access	Are there any restrictions on availability and access to the DAO's decision-making process?	Mixed assessment relating to quorum and timing: (1) How many VIAs do it take to produce a positive voting outcome for a "general" Improvement Proposal, and (2) if the voting process allows proper time and access for token holders to vote on any topic.
Reputation		
Soft power	Is there evidence of co-optation or informal manipulation?	*Qualitative assessment*: Past evidence or forward-looking assessment of how many known high-profile agents can theoretically swing a vote
Responsibility alignment	Does the DAO code or applicable norms introduce the notion of accountability for decision-makers in a fashion that appears symmetrical to the power and responsibility vested in decision-makers?	*Qualitative assessment*: No evidence of asymmetry between responsibility and accountability, for instance, unjust overruling or veto.
Accountability	Are measures for conflict and reputation management implemented?	*Qualitative assessment*: Evidence of dispute resolution measures to mitigate centralized attack vectors around reputation

4.2.1 Token-weighted Voting and Incentives

The assessment of this dimension includes:

- Analysis of whether the tokens are fairly distributed among the community, founders, and collaborators while also locking token liquidity for the future funding of the DAO's activities. Fair launch considerations include considerations over the pricing of the token across the issuance period(s). Essentially the assessment is a determination of whether the DAO's

monetary policy is fair and whether anyone, including the core team, is benefiting unfairly compared to the DAO community long term.

- When assessing whether the DAO incentivizes multilateral participation by allocating tokens to clearly differentiated stakeholder groups, it is important to notice that some collaboration and common focus are to be expected. In addition to quantifying units allocated to independent groups, the assessor could also look for signals: Is there any tangible evidence of cartel's? Is it reasonable to assume that token holders are colluding unfairly? Are big investors talking to the founders and asking them what to vote for, or the other way around?
- The concentration of voting power would include a Nakamoto-coefficient analysis of on-chain and off-chain voting history. The Nakamoto coefficient is a simple, quantitative measure of a system's decentralization [57], [58]. The coefficient is based on the Gini coefficient and calculated based on the number of critical subsystems in a system and how many entities one would need to compromise to control each subsystem.

4.2.2 Infrastructure

The assessment includes:

- Analysis of how the DAO limits large token holders (so-called whales) from having outsized influence. Some DAOs introduce the notion of time-locked voting. This allows token holders to increase the weight of their vote by locking their shares for a certain amount of time after voting has ended, trading the opportunity cost for increased voting power. Freeze and thaw measures may also be applied to the benefit of late-joiners and/or to reduce whale influence.
- Analysis of centralization of control that is not automated in a sufficiently decentralized manner, which includes an assessment of the degree of autonomy in software vs. human centrality but also a view of any single point(s) of failure or single point(s) of control concerns.
- Access is assessed both to quorum and timing, assessing how many VIAs it takes to produce a positive voting outcome for a "general" Improvement Proposal, which we could label as the Nakamoto co-efficient for governance, and second, whether the voting process allows proper time and access for token holders to vote on any topic or if (unfair) restrictions apply.

4.2.3 Governance

Assessment of governance processes is critical to determine whether there are possible centralized attack vectors in a DAO:

- Voting delegation, sometimes referred to as liquid democracy, shares the core principles of political democracy. In this case, a DAO assigns specialists to participate in an electorate with the power to make decisions on behalf of DAO members. This increases centralization, on the other hand, it may improve the quality of decision-making as in the traditional world's representative democracies. In some cases, voting delegation may constitute manipulative and/or regulatory arbitrage through conditional delegation, so the assessment should review delegation mandates to ensure the delegated mandate is not an attempt to arbitrage. The analysis can range from a simple count of the number of individual components in the DAO network and the relative size of these to more advanced network analysis and statistical tests, where a DAO uses more advanced voting delegation.
- From a narrow perspective, the assessment of voting participation analyses voter turnout participation in collective decision-making, which is a dynamic metric that may affect the security of any plutocratic governance system. Simple token-weighted voting may risk the undue influence of "whales" (large token holders). Balanced techniques adopted by DAOs include sociocracy, where decisions are made by consent, not by consensus. Quadratic voting and other alternative voting mechanisms, such as holographic consensus or multi-signature wallet (multi-Sig), are also gaining traction across DAOs. The assessment may also include a fairness assessment of the voting process, where DAOs sometimes use timing mechanisms to

reduce the risk of minority abuse. This process tackles the risk of majority voters gaining an advantage over minority voters; the downside is that the voting process becomes exceptionally long. Another method to ensure a fair voting process is "conviction voting," which is based on the community's aggregated preference and uses time as a utility to strengthen "conviction" to one's vote. A third example includes express voting that may encapsulate intensity or broader community support and thereby reduce the costs of democratic coordination.

- Sometimes, DAOs establish a foundation to own rights that can not easily be decentralized. Although this implies a centrally controlled activity, it should be viewed in context and be considered acceptable if the purpose of the centralized effort is only to bootstrap the journey towards decentralization. Outsourcing also includes software deployment strategy and hosting policy, where, according to statista.com [59], more than 64% of the world's cloud market is currently controlled by three dominant vendors (AWS, Google, and MSFT), who therefore likely host most of the blockchain/Web3 infrastructure that exists, including full nodes, validator nodes, and middleware. This is potentially a significant attack vector for censorship and centralized control.

4.2.4 Escalation

Consideration of the following issues helps in assessing escalation:

- A DAO is only as decentralized as its crisis mode allows. Hence, the assessment should investigate how control measures can be centralized in any crisis. A crisis should be defined through stress testing of the DAO business system and financial and technical resilience. Crisis mitigation and contingency measures should preferably be specified in the DAO constitution or policies for events that can impact the long-term sustainability of the DAO. Some centralization is expected to deal effectively with crisis containment, where fluid democracy may not always be the most efficient. Still, the assessment should determine the extent to which such centralization is subject to democratic control.
- An inflationary token model adds new tokens to the market over time, often through a schedule or as mining rewards or for specific contributions. For the determination of decentralization, the critical assessment point is that any value associated with inflation or deflation benefits all token holders fairly, not for the benefit of non-collaborative agents for any strategic or other participation.
- Availability and access should be equal to all, so any restrictions in access to the DAO, including its decision-making process, may suggest a level of centralized control. The assessment would include a Nakamoto coefficient analysis for both on- and off-chain activities around voter activity and token holdings and a review of voting policies.

4.2.5 Reputation

For assessment of reputation, the following considerations are suggested:

- Soft power through co-optation or informal manipulation is an everyday phenomenon in politics. In DAO communities that allows actors to engage pseudo- or anonymously, it is critical to assess that these features are not used manipulatively. Again, the analysis may potentially involve sophisticated network and statistical analysis.
- DAOs cannot act outside their rules, but because their smart contracts may contain errors or unforeseen events may occur, rule change mechanisms are necessary for resilience purposes. On the other hand, fully decentralized DAOs must also acknowledge their delegated mandates, with accountability following delegated responsibility.
- Increasingly, DAOs implement dispute resolution mechanisms or use dispute resolution services from emerging online third-party decentralized dispute resolution service providers. Other measures, such as implementing tools like Sourcecred [60] to create trust in the

community, or slashing to penalize unwanted behavior or dishonest validation, are similar mechanisms of democratic control designed to incentivize network participation.

5 Evaluation

The artifact evaluation was conducted two-fold; First, we field-tested the general concept with a DeFi expert from an EU-based supervisory authority. Second, we applied the TIGER framework to a prominent DAO using publicly available sources.

The field-test evaluation emphasized a pragmatic approach favoring comprehensive coverage of topics of regulatory concern rather than the collection of quantitative data. The introduction of partial compromisation having a full impact on the overall assessment result was deemed justifiable but raised several questions, including (1) how to deal with the lack of a grace period in the current implementation of the recently released MiCA package and (2) how to create a level-playing field for "institutional DeFi" (where traditional, currently regulated financial institutions offer decentralized financial products operated by DAOs).

In the remainder of this section, we present a sample evaluation of a DAO as a reference guide to how regulators or industry participants may approach the discretionary application of the TIGER framework.

We use the Compound protocol and its associated governance processes for the sample evaluation. It is important to note that the sample application provided here serves only as a reference guide due to the lack of access and transparency for internal data. While DAO governance primarily happens in public fora, a regulatory authority would arguably have access to a wealth of quantitative and qualitative data provided and collected by the counterparty and its partners.

While this level of access is not attainable in the academic context due to privacy regulations, the level of public governance data available is sufficient in providing a cursory reference application of the framework. Further, if a DAO is already decentralized before enforceable regulation is agreed upon, a regulator/supervisor will need to rely on the same publicly available information we access here. The Compound protocol offers an interesting entry point to the evaluation of the TIGER framework, as the protocol team was amongst the first to issue a governance token (COMP) and the adjacent infrastructure, which led to the present generation of DAO governance.

While stablecoin issuer MakerDAO had already issued their governance token (MKR) years prior, the Compound team was amongst the first to explicitly link the issuance of the token with the usage of the protocol in a bid to incentivize liquidity provisioning. This sparked a period of rapid escalation, commonly referred to by industry observers as "DeFi Summer," in the 3rd Quarter of 2020 as the major decentralized exchange Uniswap (UNI) immediately followed suit in a bid to defend market share against aggressive attempts at siphoning liquidity by the rapidly emerging competitor "SushiSwap" (SUSHI). The ensuing period saw waves of governance tokens enter the market, mimicking the previous ICO frenzy [61].

5.1 Introducing the Compound DAO

Compound [62] is an on-chain market for peer-to-peer lending, enabling users to collateralize and borrow against a selection of 18 assets. At the time of writing, the protocol manages ~€3.7bn in collateral assets deposited by ~300 000 depositors, of which ~9000 users have taken out an aggregate of ~€895m in outstanding debt against their deposits.

Protocol decision-making is governed by token-holders utilizing the token (COMP) within the governance contract. The Compound Governance process involves submitting pre-deployed code changes to risk management and asset modules above, which stakeholders can then inspect and vote for or against implementing in binary voting sessions. Proposals are generally used to

implement system parameter modifications, but proposals for adding new markets or entirely new features are occasionally implemented as well.

Further in this section, we present a cursory application of the TIGER framework, utilizing a score-card methodology in which we assign a score between 1–5 for each dimension. While there are clearly identifiable areas of improvement, we assess that the Compound DAO is *sufficiently* decentralized when we factor in the protocol age. Over time, we expect a gradually increasing decentralization as the protocol matures and increasingly larger private and institutional stakeholders join the DAO.

The overall score of our assessment is 3.8 on a scale of 5, split on each aggregate dimension as appears in Figure 5, with no critical dimension failing. A detailed assessment follows below.

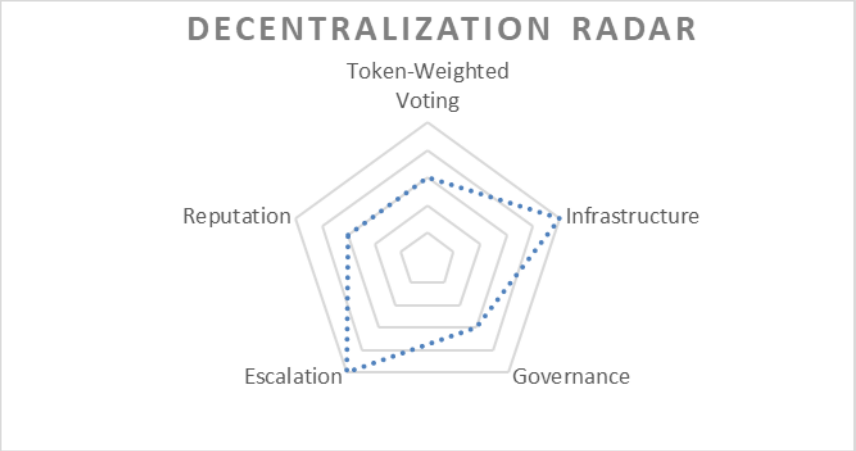

Figure 4. Compound decentralization radar

5.2 COMP Token Weighted Voting Distribution

The COMP token has a max supply of 10m units, of which 7.15m is in circulation at the time of writing. The COMP supply has a daily inflation rate, currently set at 1139 COMP daily, distributed across market participants (Table 4), alongside a 4-year vesting period for insider shareholders ending in June 2024.

Table 4. COMP allocation to stakeholder groups[†]

Stakeholder Groups	COMP Allocation	Percentage of Total Supply
Shareholders of Compound Labs, Inc.	2 396 307	23.96%
Founders & team	2 226 037	22.26%
Future team members	372 707	3.73%
Users	4 229 949	42.30%
Community Allocation	775 000	7.75%

As evident, the COMP tokens allocated to shareholders in Compound Labs, Inc. Founders and team members (present and future team members) comprise a narrow minority share of 49.95% of the total token supply, assuming that the recipients retain all tokens after vesting.

While the narrow minority does not technically produce a concentration of voting power in the hands of stakeholders with presumed shared interests, it should be noted that in the theoretical

[†] https://messari.io/asset/compound/profile/supply-schedule

event of a highly contentious issue between insiders and (external) community members, challengers would need to mount 50.05% of the token float to push through a decision, which is deemed unlikely.

Yet, the distribution of tokens amongst smart contracts and agent types [63] is such that, at present, only a few VIAs retain an adequate amount to mount a hostile proposal process. On this basis, we assign a passing score of 3 out of 5, informed by the relative concentration of votes.

5.3 COMP Infrastructure Assessment

The Compound team has implemented a well-reasoned and simple user interface for the governance process, enabling non-technical users to participate in the governance process.

The Compound Governor and Timelock methods require the deployment of code with the proposal submission. From proposal submission through voting and the mandatory two-day delay following a successful vote, the governance process implements a full week period for any decision made by DAO stakeholders.

In contrast to the frequently used option of using the popular tool Snapshot [64] to collect votes through signatures, this methodology mitigates the need for a single or multi-signer solution which can be required to implement the results of the vote when using Snapshot. Instead, approved proposals are immediately implemented by the contract once they pass. While this methodology has previously imposed costs on voters due to the high execution fees on the Ethereum blockchain, the team has implemented the casting and delegation of votes by offline signatures [65], mitigating voter apathy and improving accessibility of governance participation. Delegation functionality is implemented in the COMP token contract and delegates the voting power for the tokens from one address to another. Users interested in delegating voting power to multiple delegates can split tokens over multiple accounts and delegate to multiple delegates. The COMP token smart contract does not allow freezing addresses, manipulating balances, or upgrading the contract code through upgradeable "proxy contracts."

On this basis, we assess that the Compound governance model and the associated smart contract infrastructure are sufficiently decentralized, yielding a 5/5 score.

5.4 COMP Governance Dynamics

The Compound governance model utilizes delegation strategies, through which token holders can delegate voting power to active participants. To create a proposal, an address must hold in excess of 25 000 COMP (€1.5m) or lock 100 COMP (€6000) to create an "autonomous proposal," which can become ratified if delegated an excess of 25 000 COMP.

Governance proposals are time locked in review for three days, after which voting is initiated for an ensuing three-day period. Proposals gathering a majority of votes with a lower threshold of 400 000 COMP votes are queued for implementation for two days.

The governance of Compound is primarily in the custody of the delegate VIAs, retaining an aggregate of 92.6% of voting power with 2 377 404 COMP tokens in delegation. Of the top 60 delegates, accounting for 99.9% of the total voting weight, there is no additional delegation, so it is fair to assume the said VIAs also control these tokens.

The VIA delegates yield decisive authority over the Compound protocol, for which approximately 70% of the 36 proposals decided upon in 2022 (including failed and canceled votes) were decided by less than ten delegates wielding a clear majority. So far, in 2022, on average, ~600 000 COMP was active in each proposal, again mainly controlled by VIAs.

Through the lifetime of the DAO, 113 proposals have been voted upon, averaging 2.3 per month. The average voter turnout has increased slightly over time to 66 participating addresses per proposal in 2022, up from 56 addresses per proposal in 2020, the first year of operation [66].

Based on this assessment, it appears evident that while Compound governance is managed by a relatively small subset of VIAs with, in most cases, presumed identical preferences, said

stakeholders would be unlikely to mount a hostile proposal against users, given the token distribution.

On this basis, we assign a passing score of 3 out of 5, informed by the relative concentration of votes.

5.5 COMP Escalation and Crisis Management

The Compound governance system uses timelock to introduce sufficient time for careful review of the proposal code before implementation. The community implemented an automated "Proposal Threshold Alert" as an early indicator of potential governance attacks. The alert informs the community if a wallet has accrued sufficient COMP to meet governance thresholds. Further, the Compound Comptroller contract includes elements of a crisis management mechanism with a pause guardian. Compound Labs previously controlled this, but since 2021 transferred it to a community multi-Sig wallet created by community members, where a small group of 4–6 stakeholders, chosen by the community, can pause Mint, Borrow, Transfer, and Liquidate functions. In our understanding, this does not constitute a complete "emergency shutdown" mechanism, so we assess that the multi-Sig does not provide full crisis management capability.

The lack of any special escalatory privileges awarded to early stakeholders became evident early in the life of the protocol when a bug in a proposal placed 280 000 COMP tokens at risk of emission to liquidity providers. While the Compound team removed the ability for users to claim these tokens through the interface, this did not stop users from simply interacting directly with the smart contracts.

In what appears to be a somewhat misguided attempt to return the tokens to the protocol, the founder of Compound Labs, Robert Leshner, threatened to collect information on non-cooperative stakeholders to inform the US tax authorities [67]. While these attempts were ridiculed by the community members, the case resembles the user B situation in Figure 1 above. It provides an example of how all stakeholders, regardless of their seniority in the community, cannot influence decisions governed through smart contracts.

Based on the lack of discriminatory privileges awarded to key stakeholders, outside of the ability to amend the contract web interface, we assess that the Compound DAO is sufficiently decentralized on this dimension, yielding a score of 5/5.

5.6 COMP Reputation and the Impact of Soft Power on Decision-Making Processes

Compound governance primarily occurs in designated online fora, where governance participants pitch and discuss proposals before developing and deploying a proposal code. Discussions are generally cross posted on social media [68] with parallel discussions occasionally led on chat servers [69]. On average, new posts are submitted daily to bi-weekly, indicating a moderate to high activity level.

By cross-referencing with data from LinkedIn [70], we note that the official organization appears to employ 19 employees with titles indicating a commercial relationship with Compound Labs Inc. We did not find evidence of any inordinate influence in proposal submissions by these employees. However, the picture is different when we assess the influence of large vs. small token holders in what we presume is the primary governance forum [71] for pre-proposal discussions: Out of a total of 113 proposals to date, 97 are included in the pre-proposal discussion. Of these, at least 53 posts have been authored by individuals in founding roles or with clear connections to the founding team or major token holders. Of these 53 posts, 32 were authored by the service provider Gauntlet [72], a firm specializing in financial modeling, which previously completed a market risk assessment report on Compound [73]. Gauntlet is identified as the controller of the fourth biggest delegate address, yielding 118 494 COMP at the time of writing this article. While Gauntlet is a frequent and active participant in Compound governance, the primary emphasis is on topics clearly

related to risk management or the addition of new assets to the platform and does not appear manipulative.

There appears to be no dispute resolution mechanism. In the Compound chat forum on Discord; this has been debated, with some community members objecting to any dispute resolution mechanism and others firmly in support. The topic has not been subject to a formal vote. On this basis, we assign a score of 3 out of 5 on this dimension.

6 Discussion

In this article, we propose an information system (IS) focused conceptual artifact based on a review of the literature, combined with expert insights from a group of industry stakeholders and experts. The artifact demonstrates the feasibility of structured assessment methods of the level of DAO decentralization both on-chain and off-chain, mapped to generalized, critical processes of DAOs. We address the research question: "When is a DAO (sufficiently) decentralized?"

In analyzing whether a DAO is sufficiently decentralized, we might expect some quantified evidence of chaos, swarm, and/or a self-organized, distributed, decentralized community, as opposed to an ordered, strong organization with centralized command and control that characterizes the traditional organization.

Hence, the critical focus of analysis is whether the DAO stakeholders or "actors" are empowered with delegated authority and whether they operate sufficiently independently of each other and in their own self-interest in an uncoordinated and voluntary manner.

We propose that "sufficient decentralization" is defined as a verifiable state, where the design of the DAO (1) is collusion resistant and based on long-term equilibrium, and (2) its governance processes have unrestricted and transparent access.

From a regulatory perspective, an alternative approach could simply be to analyze (1) if the DAO is conducting a regulated activity, and if so, (2) if there is an accountable legal or physical person upon whom regulation can be enforced; if not, then DAO being sufficiently decentralized has to be acknowledged. In our view, such an approach is too simplistic and does not accept the fundamental premise that DLT/Blockchain is a transformative technology that will foster innovation and growth.

In terms of conciseness and robustness attributes of the assessment framework, the challenge lies in the complexity of decentralization as a concept. We avoid an extensive classification scheme that could lead to cognitive overload when assessing a given level of decentralization point in time while also defining enough dimensions and characteristics to clearly differentiate the objects of interest [55].

From a practical and theoretical perspective, it seems evident that no DAO can start decentralized, as any project must be initiated by a small core team, bootstrapping development until the project matures and attracts open-source contributors. However, as discussed, the European regulators did not play any particular emphasis on this critical point when agreeing on the final text of the MiCA regulation. Some US regulatory proposals suggest a safe harbor rule [25], proposing a grace period to allow a DAO to become sufficiently decentralized, thus introducing the concept of "gradual decentralization." In our proposed assessment framework, we acknowledge this by suggesting that the assessment includes a perspective on the mature DAO design, not just the point-in-time view.

We extrapolate our contributions into the following generalized propositions:

P1: The concept of technology-neutral regulation is challenged by DLT/Blockchain. DAOs exist and realize benefits through increasing degrees of decentralization. DAO legal design should therefore support the internal decentralization accomplished by the DAO so that a balance is achieved between external and internal decentralization [11], not the other way around. When regulators in the coming years design technical requirements for the supervision of DAOs, they need to acknowledge this underlying premise and embrace that DLT/blockchain is a transformative technology that requires unique regulatory approaches.

P2: Regulators need to embrace the concept of a "grace period" for a DAO to achieve sufficient decentralization. The MiCA regulation did not include this, but it seems challenging to embrace DeFi and the concept of sufficient decentralization without it. We suggest an assessment approach where not only the point-in-time assessment is material to the decision of decentralization but also the design intent, thereby introducing a grace period from a risk-based perspective, allowing the EU to practically align crypto regulatory compliance to the safe harbor proposals from the US [25] and common sense.

P3: In the short term, for "Institutional DeFi," a level playing field needs to be developed by financial regulators and supervisors, including a "cut-off" strategy, with clear boundaries for acceptable centralized activity, to allow DLT/Blockchain-based businesses to develop properly, respecting the new technological feature regime. From a regulatory perspective, and in the words of MiCA, complete decentralization seems to require full automation. Still, when elements of human governance are introduced, it is difficult to think of complete decentralization as outlined in MiCA. Some automated features also become centralized through the front-end website hosting or other elements. Regulators must accept that a new playing field for DAOs will develop over the coming years.

P4: Regulatory practices around DAO decentralization will evolve across blockchains and business models, each with its own strengths and weaknesses regarding centralized attack vectors and regulatory importance. A risk-based approach to DAO supervision, where required, will therefore need to be developed with a holistic view of decentralization across political, technological, social, and economic dimensions, as well as across underlying technology infrastructures that behave very differently from a risk perspective. We foresee regulators will designate some blockchains to have more systemic risk than others.

P5: DLT/Blockchain will transform how regulators supervise and enforce the regulation. The number of DAOs grew by a factor of 8x in the past year [74]. With the increasing certainty on the regulation of crypto, the number of DAOs will likely continue to evolve, and the growth of the token economy and innovation of blockchain-based business models as well. Some sample DAO business models [76], [77] are listed in Appendix 1.

These developments pressure regulators to keep pace with developments in two dimensions: (1) Supervisors with a traditional finance focus will be challenged as their supervisory toolkits and skillsets become disconnected and obsolete. Regulators and supervisors must embrace the available and emerging investigative techniques to analyze DAO structures and processes in real-time, on- and off-chain; (2) A focus on automated and embedded supervision should be prioritized [75].

Our work contributes to practice by identifying criteria for DAOs, regulators, and supervisors to consider when assessing whether a DAO is "sufficiently decentralized," complementing the understanding beyond technical difficulties by taking a holistic view of DAOs as complex socio-technical systems.

Our findings contribute actionable insights to the information system literature by emphasizing how DLT and blockchain technologies may be assessed from a socio-technical perspective. We contribute to DAO communities and regulators with a pragmatic tool to understand to what extent an otherwise regulated activity may be considered sufficiently decentralized and thereby avoid significant and costly compliance requirements.

7 Conclusion

We investigate the topic of decentralization as it relates to DAOs, using a thematic analysis method to identify relevant patterns to assess whether sufficient decentralization is presented. Through the framework's design, we demonstrate the feasibility of implementing a structured method for the assessment.

We propose a definition of "sufficient decentralization" and incorporate the notion of a representative democracy via delegated mandate in the assessment framework. Still, it remains to

be concluded what level of delegation and decentralization is acceptable under different regulatory regimes. Some regulators seem to suggest complete decentralization as the only acceptable level. However, complete decentralization in DAOs is challenging to grasp, as they are socio-technical constructs.

We design a generalized assessment framework with suggested quantifiers. Still, the application of all characteristics and levels of quantified assessment will likely vary, depending on the need for regulatory monitoring by jurisdiction. Hence, the framework design is flexible to accommodate change as regulatory practices evolve and regulatory technical standards become defined. We demonstrate the practical application of the framework artifact by assessing the level of decentralization of Compound, an algorithmic money market DAO operating on the Ethereum blockchain.

Our findings suggest that decentralization in DAOs is not a myth. Still, due to the technical features of blockchains, it can be complicated to investigate and assess the true level of DAO decentralization. Our contribution is a pragmatic framework that can guide aspiring DAOs, regulators, and supervisors to advance the decentralization agenda as the crypto and traditional economies increasingly overlap and integrate. We extrapolate the findings into five general propositions on the implications of decentralization on the supervision of regulated financial activity in crypto.

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Appendix 1 – Sample DAO Business Models

Category *	Description
Media DAO	Media DAOs such as Mirror (https://mirror.xyz/) empower writers and make it possible to work alone or collaboratively to publish, crowdfund, and create auctions and editions of media projects or digital artwork through tokens.
DAO Operating system	DAO operating systems or "platforms" such as Aragon (https://aragon.org/) or DAOstack (https://daostack-1.gitbook.io/v1/) provide a complete software stack and infrastructure for building and running a DAO, including various apps for token management, voting, and finance.
Social DAO	The Social or Community DAO category covers a broad range of DAOs that focus more on social capital than financial capital; they include communities that evolve from group chats to co-working DAOs or just a meeting place. An example is Filmmaker DAO (https://www.filmmakerdao.com/), which coordinates filmmakers' efforts to enable more IP ownership.
Protocol DAO	Protocol DAOs were initially intended to transition power from a founder team into a broader community, finding new ways for projects to issue fungible tokens into the market. These DAOs now constitute the bulk of decentralized finance (DeFi) protocols, such as Aave (https://aave.com/), Uniswap (https://uniswap.org/), or MakerDAO (https://makerdao.com/) and typically with a transaction focus aiming to compete with traditional finance.
Collector DAO	Collector DAOs are the home of NFT art-focused DAOs, such as PleasrDAO (https://pleasr.org/) enable their community to share the cost of expensive assets and co-own digital art, in the case of PleasrDAO specializing in what the members determine are culturally significant art pieces, that are further fractionalized for trading on DeFi protocols such as Uniswap v3 NFT.
Investment DAO	Investment DAOs such as Seed Club DAO (https://www.seedclub.xyz/) enable their community to co-invest, build and accelerate digital communities, land, or other assets deemed relevant for an investment focus.
Impact DAO	Impact DAOs, such as Climate DAO (https://climatedao.xyz/), focus on sustainability and conservation agendas. They are frequently driven by activist communities collaborating with research institutions or having educational activities.
Service DAO	Service DAOs, such as BrightID (https://www.brightid.org/) support DAOs with all required infrastructure and operational services, for instance, token, governance, or operational services, including voting, recruitment, legal, risk management, community management, technology, treasury, or, in the case of BrightID, a decentralized digital identity DAO.
Grants DAO	Grant DAOs such as Gitcoin (https://gitcoin.co/) enable their communities to donate funds and vote through governance proposal rounds on how the distributed funding capital is allocated to various projects, typically focusing on digital common goods aligned with Ostrom principles and not for profit.

* Sources: "DAOs List - Messari." https://messari.io/governor/daos (accessed Jul. 24, 2022) and "Full-Time DAOs — Coopahtroopa." https://coopahtroopa.mirror.xyz/5vTIKBRzMpVAiNyc7CnABXjh3ToJrjQOnOdkwqvb3l8 (Accessed on Jul. 24, 2022).

HOW SHOULD DAOs BE REGULATED?

A NEW PERSPECTIVE ON DECENTRALIZATION

Authors

Henrik Axelsen and Omri Ross

On 8 August 2022, the US Department of the Treasury's Office of Foreign Assets Control (OFAC) sanctioned Tornado Cash, a so-called currency mixer used to obfuscate the otherwise transparent money trail on the Ethereum blockchain. The service was said to have laundered more than US $7 billion in illicit funds, of which $455 million were initially stolen by the Lazarus Group, an infamous hacker group with alleged ties to the North Korean government.[1]

Curiously, Tornado Cash is an open source software project comprising several smart contracts deployed on the Ethereum blockchain. Users of Tornado Cash operate independently by sending funds through smart contracts, which encrypt the money trail by submerging the funds in a liquidity pool from which the sending user can withdraw an equivalent amount of funds to a brand-new address with no prior money trail.

How is it possible to sanction an autonomous smart contract, and how will the precedents set by today's enforcement actions impact the future of the decentralized autonomous organization (DAO)?

ENTITIES OR ACTIVITY?

The acronym DAO is typically used to describe a hybrid form of a community-based organization that relies on open sourced smart contracts, primarily on the Ethereum blockchain. The coordination of work usually relies on a token-based economy and primarily emphasizes the design and development of products that resemble financial services. Hence, the majority of DAOs relate to financial technology (fintech).

Fintech has long been a driver of transformation and digitization in the financial services industry. This has led to a global debate on whether or not the success of such fintech firms is due to lighter regulatory capital requirements than traditional financial institutions and the appropriate policy response.[2]

Although many questions on how to regulate fintech and crypto remain, the OFAC sanction challenges the status quo. It is the first time open source software has been listed on OFAC's Specially Designated Nationals and Blocked Person List as a sanctioned "person."

The OFAC sanction has potential implications for the regulatory paradigm surrounding DAOs. In this article, we discuss and evaluate some of the implications of this action.

> **FINTECH HAS LONG BEEN A DRIVER OF TRANSFORMATION AND DIGITIZATION IN THE FINANCIAL SERVICES INDUSTRY**

EVOLUTION OF WEB3 & REGULATORY PLAYING FIELD

A blockchain is a distributed database, or ledger, operating on many independent computers (nodes), each holding a full replica of the database to validate transactions.

In permissionless blockchains, access is unrestricted, and anyone with an Internet connection can compute transactions on the network and read the state of the database.

The Ethereum blockchain introduced the notion of smart contracts and remains the primary network on which DAOs operate and produce decentralized applications. Interestingly, smart contracts are neither smart nor contracts but merely code deployed to the blockchain that executes a given logic in the replicated database maintained by the blockchain.

The key difference from a regular agreement is that the blockchain itself executes the code automatically. This means that once a smart contract is deployed, no human engagement is required to complete the transactions or other business logic denoted by the contract code.

Because the network of nodes that maintains the blockchain is decentralized, the propagation of transactions and deployment of smart contracts is a one-way street. Since there is no central intermediary keeping tabs on the behavior of the nodes in the network, it is not possible to reverse transactions, as this would require a mechanism of arbitration, which would run counter to the concept of decentralization.

This means that, once deployed, the smart contract will execute for as long as the version of the blockchain exists; it cannot be turned off.

Smart contracts made decentralized business models between untrusting counterparties possible by allowing the computation and atomic execution of agreements without human involvement. This introduced the notion of the decentralized application (colloquially referred to as a "dApp"), which computes various financial functions within the blockchain database.

Since the first dApps primarily serve financial purposes, they are typically associated with the decentralized financial (DeFi) movement[3] and compute features such as the exchange of assets at algorithmic price ratios[4] or the trading of art pieces linked to non-fungible tokens (NFTs).[5]

Decentralization usually refers to the physical distribution of active stakeholders asserting political influence over the network. This implies an organization of individuals operating without any hierarchical architecture in a fluid organization designed to promote equilibrium conditions between stakeholder groups with differing incentives.[6]

SAME ACTIVITY — SAME REGULATION?

"Same activity, same risk, same regulation" is a slogan often used in traditional finance in response to large technology firms' entry into what is perceived as an exclusive market.[7]

Global policy setters like the Financial Stability Board generally oppose activity-based regulation regarding prudential matters (i.e., matters related to financial stability, capital, and liquidity).

Although policy setters acknowledge the necessity of an activity-based regulatory approach in other matters, such as anti-money laundering, it's often suggested that the notion of a level playing field is secondary to other public policy objectives, such as financial stability, market integrity, investor protection, and preserving monetary sovereignty.[8]

From this argument, we draw the tacit conclusion that entity-based regulation should be the primary approach for prudential matters, restricting market access only in cases where primary policy objectives are perceived as threatened.

IS A TECHNOLOGY-NEUTRAL REGIME APPROPRIATE FOR DAOs?

As DAOs frequently operate DeFi applications, several DAOs have reaped immense profits from the rapid growth of this sector and now control treasuries worth billions. This somewhat drastic turn of events has led some regulators to imply that the operational aspects of DAO governance, which typically involve the issuance of new governance tokens to fund development initiatives, fall under the definition of regulated financial activities.[9]

It should be noted that, if applied without discretion, existing regulations would impose an excessive compliance burden on young DAOs: founders would be compelled to follow complicated controls, oversight, capital, liquidity, and reporting requirements equivalent to those observed by modern financial institutions.

Thus far, regulators have referred to a principle of technology neutrality, denoting an emphasis on what happened rather than how it happened.[10] For this reason, technology-neutral regulation tends to emphasize purpose and function, subject to context and interpretation.

The somewhat radical notion of deterministic automation challenges this otherwise commonsense principle. In most cases, the only identifiable agency in the interaction between a natural person and a set of smart contracts is the natural person him/herself. Because persons interacting with the smart contracts do so entirely of their own volition, it is hard to argue that the individual who developed and deployed the smart contract should be held responsible for its use.

Consequently, an attempted application of the prevailing regulatory paradigm results either in highly invasive regulation, which is not fit for purpose, or no regulation at all. This explains why regulators are still playing catch-up more than a decade into the emergence of blockchains.

In cases where no discernable entity can be identified, regulators acknowledge the competitive potential and innovative nature of DAOs as transparent and decentralized entities operated by pseudonymous agents governed by equal rules.

Lacking specific regulation of DAOs, regulators currently accept the concept of "sufficiently decentralized" as a means of avoiding the requirements for enforcement actions against noncompliance, even if the opinion is that a DAO is undertaking an otherwise regulated activity.[11]

REGULATING EXACTLY WHO, WHAT & WHERE?

Regulators in the US and EU both adhere to the principle of technology-neutral regulation, but both struggle with the implementation and seem to iterate between entity- or activity-based approaches, resulting in what may be considered an aggressive approach.

In the aforementioned Tornado Cash case, OFAC broadly sanctioned all known wallets that had previously interacted with the protocol, as well as other connected wallets identified from the hacking events, several websites linking to Tornado Cash, and, most interestingly, the open source smart contract code itself.

This led to a broader disruption of the decentralized financial system, as entities and individuals that had no relations with Tornado Cash suddenly found themselves sanctioned by the US Department of the Treasury because the audit trail of a token they own or control implicated a connection to Tornado Cash.

The impact of these sanctions reverberated far beyond the sanctioned individuals in scope, attracting media attention from newscasters around the world.

Although the source of the decision is unclear, it is to be presumed that the choice of issuing blanket sanctions was made due to: (1) a lack of appropriate regulation to enable proactive review, evaluation, and intervention in a proper format and (2) the inability to identify any definite legal subject, alongside growing concerns about the illegitimate activities conducted using Tornado Cash.

Hence, OFAC appears to have initiated a shift from a technology-neutral perspective toward a technology-specific intervention, resulting in an attack on the broader crypto ecosystem.

In a litigious society like the US, this regulatory sanction has already led to lawsuits focusing on constitutional rights, free speech, privacy, and stifled innovation.

Perhaps as a result, the regulator is now backtracking its initial blanket sanctions, publishing a statement suggesting that "interacting with open source code itself, in a way that does not involve a prohibited transaction, is not prohibited."[12]

Turning to the EU, we are witnessing a less direct approach. The recent Markets in Crypto-Assets regulation (MiCA) makes no explicit mention of either DeFi or DAOs but instead introduces a general terminology for the otherwise abstract concept of decentralization.[13]

The regulation focuses on the issuance of certain crypto assets and services provided to these. And it allows otherwise regulated activity if it is "sufficiently decentralized" within the appropriate context.

This raises the question of what happens to "sufficiently decentralized" DAOs that infringe on the regulation when regulation comes into force, including DAOs that may already be operating a regulated crypto asset covered by the regulation within the EU. Could European regulators shut down an entire ecosystem, as was the case for Tornado Cash?

The short answer might be yes, as MiCA enables authorities to suspend a regulated crypto asset if it's operating in conflict with the rulebook. The regulation allows authorities to suspend it directly or indirectly via the associated ecosystem.

If the infringing activity is carried out by a "sufficiently decentralized" DAO, the regulator will not be able to hold anyone accountable. In this case, the crypto asset service providers, such as exchanges or on- and off-ramp services, can be asked by the regulators to suspend services to the DAO.

A WAY FORWARD?

Until recently, it was assumed that DAOs could operate outside the scope of compliance if sufficiently decentralized, a belief challenged by recent regulatory actions. Still, when one path closes, another opens.

The first question to ask is about the purpose of decentralization and business scope in any given DAO. Suppose the answer is mainly to gain an unfair advantage in what resembles traditional financial activity by having no capital or liquidity constraints, controls, or reporting requirements while disregarding any expectations to prevent illicit activity. This approach is increasingly becoming difficult through brute enforcement action, as discussed above.

But suppose the answer is that we have a great idea and want to build a global community around it and share not only the development effort but also the benefits, and we want to work across the globe with distributed teams of part-time contractors without having to establish legal entities with employment contracts in all local markets. In that case, the playing field for DAOs appears quite open. That is, if there is still meaning to "decentralization" as a concept in a technology-neutral regulatory paradigm.

For DAO as an organizational phenomenon, we could see an evolution toward tiers or paths based on purpose and intent. One path would be for DAOs with a transactional, for-profit purpose, with activities resembling regulated financial activity to accumulate and distribute profit based on the effort of others. A second path would be for DAOs in which the token economics required to incentivize the community serve a completely different intent, and the DAO format and blockchain technology just enable a better method to achieve the desired outcomes.

DAOs AS REGULATED PARTNERSHIPS

Many jurisdictions may consider unregulated DAOs equivalent to unregistered general partnerships, meaning that individuals may face potentially unlimited liability. Along these lines, a very recent US Commodities Futures Trading Commission (CFTC) enforcement action found not only a DAO liable for violating the US Commodity Exchange Act rulebook, but also two individual token holders personally responsible for violations based on so-called control person liability, a local US phenomenon.[14] This personal liability was established based on the individuals' status as voting token holders of the DAO in question.

A lot can be said of this enforcement decision, and a dissenting commissioner also argued that the CFTC enforcement action was wrong and unsupported by legal theory, as, among several issues, it defined the DAO unincorporated association as being the token holders, who vote with their tokens at any given point in time. The resulting effect is distinguishing between token holders based on an arbitrary principle not found in the law. Nevertheless, this was a dissent, and the enforcement action confirms there is a real risk for individual token holders in unincorporated DAOs.

Hence, a legal industry to help DAOs ring-fence liability with "legal wrappers" for personal indemnity protection is developing. Some might consider such legal wrapping as a step toward centralization. However, from a regulatory perspective, this option appears appropriate.

From a commercial perspective, legal wrapping relates to the autonomy and ability of a DAO to engage with other parties rather than a question of decentralization, per se. Legal wrapping or incorporation may be a natural step forward for DAOs with plans to engage and interact with the traditional, for-profit world with an activity that resembles regulated financial activity.

Incorporation would be a suitable choice for DAOs aiming to disrupt traditional business processes through decentralized organizing while leveraging the DAO format to form new multi-party collaborative blueprints and develop smarter ways of working in a project-based economy with a modern form of stakeholder capitalism, better coordination mechanisms, and with a high level of automation and process efficiency.

This path can be considered an incremental innovation that does not fully replace existing organizational theory or thinking. Instead, it adapts existing paradigms to the transformative potential of the technology presented and expands with the automated features on- and off-chain as required.

FOR DAO AS AN ORGANIZATIONAL PHENOMENON, WE COULD SEE AN EVOLUTION TOWARD TIERS OR PATHS BASED ON PURPOSE AND INTENT

For example, these DAOs could become vehicles to blend capital from traditional finance and decentralized finance and create an enabling transition that finances the ecosystem using token economics, where different public and private capital sources could be brought together in technology-specific, multi-party collaborative business models to explore new ways of stimulating demand while establishing reliable, scalable supply.

> **THE CAPABILITIES OF DISTRIBUTED LEDGER TECHNOLOGY ALLOW DAOs TO DEVELOP TRULY INNOVATIVE PLATFORM BUSINESS MODELS**

An example could be a blended financing model that the world could use to transition to net-zero carbon emissions, which requires tracking the true carbon impact of environmental initiatives in rural or local areas. This market is developing, but there is a lack of integrity due to inconsistent standards, definitions, and enforcement. Blockchain could deliver the required transparency, and its tracking capabilities could assist in such a market development.

Decentralized and traditional finance could meet, with DAOs enabling the transmission of compliant financial instruments based on securitized, tokenized carbon sequestrations that allow institutional investors access where there is no access today. The intent of this business model is financial innovation, and the choice of the DAO format could be mainly due to the preference for distribution model, global reach, or simply resources, as the talent to deliver such a model would be scarce and difficult to manage in a traditional organizational format.

DAOs AS DECENTRALIZED PLATFORMS

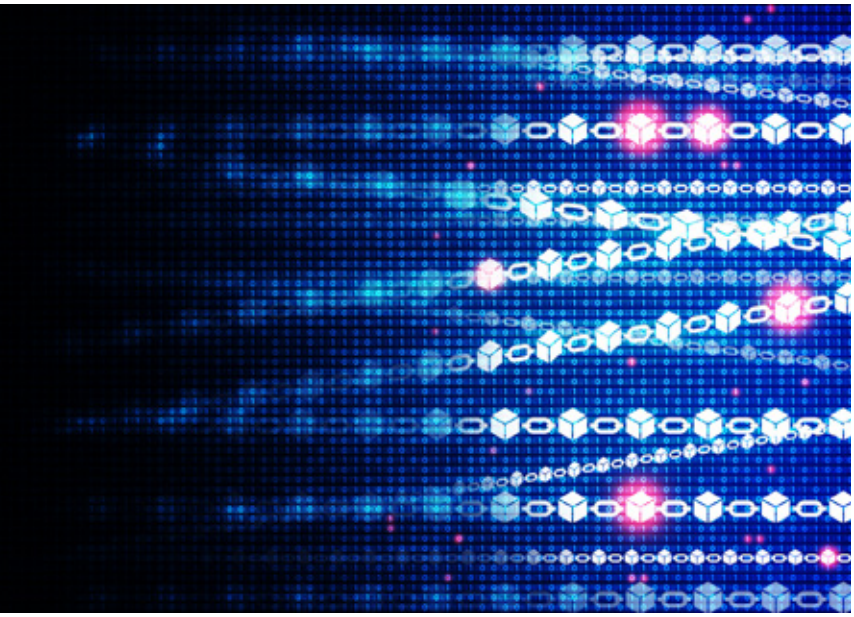
Although regulators mainly aim for financial policy objectives, they appear sympathetic to the transformative potential of blockchain technologies that reach far beyond finance's scope.

In this context, the disruptive potential of DAOs not only includes the possibility of establishing a fairer model for the distribution of wealth, it also allows new, decentralized ways of working. For example, a blockchain-based Internet makes it possible to reach the one-third of the global population that does not have access to traditional finance but does have access to a smartphone.

The capabilities of distributed ledger technology allow DAOs to develop truly innovative platform business models. Scaling via a replicated decentralized financial system embedded by blockchain may enable business innovation in places where traditional finance is either too inefficient, expensive, or too centralized or controlled to deliver optimal results.

Using the example of a blended financing model to transition to net-zero carbon emissions, a decentralized platform could leverage Nobel prize winner Elinor Ostrom's principles for self-governance of communities and explore the transformative potential of blockchain for communities to establish new contracts and ways of doing business to stimulate supply and demand based on community involvement. It would potentially leverage tokenization, self-enforcement and formalization of rules, autonomous automatization, decentralization of power over the infrastructure, increased transparency, and codification of trust.

The purpose and intent of these DAOs would likely be distinctly different from transactional partnership models in that they would focus mainly on creating a culture of relationships and collaboration. In both models, one could expect communities of fully anonymous (or, more realistically, pseudonymous) stakeholder representation. Still, where the partnership model is likely more focused on efficient voting mechanisms with delegated, verifiable mandates and professional investor backing, the platform model would likely operate in a much more distributed and fluid democracy, with open access and community management in an online forum of sorts.



These platform DAOs would likely use reputation tools to establish and manage token-based reputation credentials that would rely on the community members' (avatar) behavior on the platform and their contribution to the community, not through traditional means such as seniority or wealth. These communities would strongly resist centralized actors or collusion efforts. Their token economics would focus on funding community activities, long-term treasury operation, and the fair distribution of rewards to those that contribute according to the rules of the DAO while avoiding centralized bureaucracy, freeriding, and control. Activities would be project-based — projects would be selected based on token holder voting, and the token itself would likely be traded only on decentralized, automated markets.

The two paths outlined may overlap. A decentralized platform path does not exclude interoperability with the traditional world, and whether or not DAOs pursue the latter path as incorporated/regulated, the playing field is wide open. The key difference is some DAOs act as mechanisms of transmission (the partnership model), and others reward de facto contribution (the platform model).

The platform community DAOs should, however, keep an eye on how they interact with more mature regulated financial markets and take appropriate action where (1) they plan to trade their native token on a regulated exchange; (2) the native token aims to be supported by a stablecoin; or (3) the business model becomes material to financial stability or serves a speculative purpose based on efforts of others. Also, considering the regulatory action mentioned earlier, they should always meet global expectations to prevent illicit activity, as other organizations should.

In those DAOs, pseudonymity would have the added benefit of avoiding personal liability should voting decisions (despite good intentions) result in loss or damage to contracting or third parties working with the DAO.

CONCLUSION

Although pioneered many years ago, blockchain is still considered novel technology when it comes to innovative business models, wealth distribution, and new democratic forms of governance.

The core problem presented in this article is that the technological development around blockchain and DAOs offers a transformational shift that challenges the existing regulatory paradigm in which an identifiable legal entity is presupposed.

Despite the lack of technology-specific regulation required to deliver the full potential of this technology, and despite the lack of accelerated effort and incentivization of DAOs to meet the urgent need for innovative business models with blended capital (where DAOs and the decentralized economy could play a major role), DAOs are finding ways to maneuver into all aspects of the traditional economy because they offer communities more autonomy, decentralization, transparency, and trust than conventional organizations.

As regulators increasingly realize the transformative potential of blockchain, distributed technology, and the DAO format as an attractive alternative to traditional hierarchical structures, we hope regulators will also improve their approach. They should seek solutions for mitigating the fallacy of blind obedience, rather than acting with blanket sanctions of open source technologies or inventing new rules through enforcement actions that have a wide-reaching impact and should be subject to a proper process.

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Research Paper

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Abstract

The promising markets for voluntary carbon credits are faced with crippling challenges to the certification of carbon sequestration and the lack of scalable market infrastructure in which companies and institutions can invest in carbon offsetting. This amounts to a funding problem for green transition projects, such as in the agricultural sector, since farmers need access to the liquidity needed to fund the transition to sustainable practices. We explore the feasibility of mitigating infrastructural challenges based on a DLT Trading and Settlement System for green bonds. The artefact employs a multi-sharded architecture in which the nodes retain carefully orchestrated responsibilities in the functioning of the network. We evaluate the artefact in a supranational context with an EU-based regulator as part of a regulatory sandbox program targeting the new EU DLT Pilot regime. By conducting design-driven research with stakeholders from industrial and governmental bodies, we contribute to the IS literature on the practical implications of DLT.

Keywords: DLT Pilot regime, Trading, Settlement, Liquidity, Green Bonds, Net-Zero, Funding

1 Introduction

To achieve the UN climate conference (COP21) Paris Agreement of limiting global warming to less than 2.0 degrees Celsius and providing a significant effort to limit it to 1.5 degrees Celsius this century, the international community must reach net zero carbon emissions by 2050 (United Nations, 2015). According to global observers, the planned energy scenario to reduce these required carbon emissions may require an investment of up to USD 95 trillion (IRENA, 2020) from 2016 to 2050, with more transformative scenarios requiring even more.

Voluntary carbon markets (VCM) play a key role in this transition. Voluntary markets differ from the emissions-based carbon credit markets (so-called compliance carbon markets) by enabling the trade of carbon sequestration, avoidance of nature loss, and other efforts to reduce carbon emissions, including technological improvements. Although VCM has shown impressive growth over the past decade, the concept is plagued by two key problems: Correctly certifying the integrity of the carbon credit presents an extraordinary challenge, and the lack of a globally scalable and compliant trading infrastructure greatly limits the issuance and trade of these instruments.

This paper focuses on the second problem: Designing a scalable financial market infrastructure for the voluntary carbon markets. Both problems are intimately connected, as carbon credits' perceived and real value depends on the verifiable integrity of the underlying carbon capture certificates. We set out to explore the following research question: '*To what extent can distributed ledger technology (DLT) facilitate the issuance, trading, and settlement of regulated financial instruments (green bonds) to finance carbon capture based on verified carbon credits in voluntary carbon markets*?

Our research question naturally implies a need to understand the implications of financial securities regulation. For this reason, we worked with a team consisting of financial, agricultural, and technological experts. Some of us entered a regulatory sandbox program under the EU DLT Pilot regime, led by a Financial Supervisory Authority from an EU member state. The program aimed to assess the regulatory requirements of a novel DLT-based Trading and Settlement System (DLT TSS) based on domain-specific language technology for specifying financial and commercial contracts (Andersen *et al.*, 2006).

By conducting multidisciplinary and design-driven research, we contribute to the Information Systems (IS) discourse on the practical implications and limitations of DLT. This involves a novel DLT-based artefact addressing the need to scale voluntary carbon markets to a global group of users. We examine how DLT infrastructure may be used to scale VCM to introduce these instruments into existing trading and settlement systems. We use the novel concept of 'carbon cash flows' as collateral, originated via projects, to demonstrate the benefits of using DLT as capital market infrastructure. Defending market integrity and stability is critical to designing and evaluating a capital market infrastructure. An equally important, but distinctly different challenge, is the complexity of environmental market integrity, which we will touch only briefly in this paper as it relates to financial market integrity. The market infrastructure artefact presented here facilitates the monitoring and reporting of such strict verification and integrity standards as how marketplaces in traditional capital markets operate.

We use the Design Science Research (DSR) methodology, informing an iterative approach to the artefact design in which feedback from stakeholders representing multidisciplinary perspectives is integrated into the design specification. To this extent we aim to contribute practical insights to the growing body of IS literature demonstrating the application of the DSR methodology in the design of technical artefacts addressing the challenges of today.

2 Background

IS scholars have long promoted technologies broadly referred to under the 'DLT' umbrella for the benefits that these may imbue on regulated capital markets (Collomb and Sok, 2016) and payments in general (Lindman, Rossi and Tuunainen, 2017). The potential of DLT and Blockchain in pre- and post-trade processes is well examined in the literature, suggesting a potential for reducing costs while mitigating counterparty credit risk (Jensen and Ross, 2021) and reducing the cost of capital. Several other efficiency gains have been identified in the literature, ranging from transparency in the verification of securities holdings, mutualization data, and optimized Know-Your-Customer (KYC) processes (Parra-Moyano and Ross, 2017) in pre-trading to real-time transaction matching, execution, and reporting. The IS literature frequently uses design-oriented or case-based methodologies to explore and demonstrate how new DLT relieves or creates friction across industries. Scholars have shown how blockchain might give rise to new types of economic systems (Beck and Müller-bloch, 2018), or how the implementation of blockchain technology introduces fascinating organizational issues (Gozman, Liebenau and Aste, 2020).

2.1 The Markets for Voluntary Carbon Credits (VCC)

The voluntary carbon market differs from the general carbon compliance markets for designated carbon offsets, associated with the international efforts led by the United Nations Climate Change Convention. VCMs let developers of projects that prevent, reduce, or eliminate carbon emissions apply to private standardization organizations, which then certify the emissions avoided, reduced, or eliminated by the project. Developers create voluntary carbon credits (VCCs) through a designated certification process in which one VCC represents one ton of CO2 emission captured or avoided. The VCCs are stored in a registry maintained by the organization that certifies the project. To claim the reductions, the developer can either retire the credits to offset CO2 emissions or transfer them to another organization with an account in the registry.

In simple terms, the business case for VCCs is to unlock funding for those willing to commit to the preservation of the cultivation of forests or other events leading to the increased sequestration of carbon from the atmosphere. Let us consider an example: A small farmer is looking to transition from current farming methods to regenerative farming methods. To do so, the farmer will need to acquire new machinery and other types of seed, which will introduce several new expenses. The new regenerative

farming methods will typically result in reduced crop yield for a few years before producing results like non-regenerative methods. As a consequence of the transition, the farmer will face increased costs and new risks to her existing revenue streams. By sourcing new revenue streams through the sale of carbon credits, the farmer can make up for the shortfall over time. Indeed, bridging this liquidity gap is in the global community's shared interest, as the lack of financial incentives is a major obstacle to accelerating the transition to Net Zero. Yet, because of the issues outlined above, small and medium enterprises (SME) are disincentivized from pursuing a green transition. Collateralization of future green cash flows through so-called Asset-Backed Securities (ABS) is gaining prominence but has yet to reach SMEs (Global Capital, 2022).

In recent years, global initiatives such as the Taskforce for Scaling Voluntary Carbon Markets (TSVCM, 2021) have been mandated to accelerate growth in these markets. In addition to proposing integrity principles for voluntary carbon markets, the TSVCM and now its successor, the ICVCM, suggests that new infrastructure is needed to provide the backbone for trading, clearing, and settlement of VCC, coupled with new funding solutions that can produce transparent market and reference data. The suggestions emphasize meeting the increasing supply and demand for VCC by building (1) exchanges that will manage Core Carbon Principle aligned credits to enable increased liquidity and ease of purchase, (2) post-trade infrastructure, including the design and supervision of a meta-registry to bolster market integrity and market functioning, and (3) advanced and transparent data infrastructure with shared protocols that are widely accessible.

2.2 Is Blockchain Technology the Solution?

Recent years have seen several attempts at using blockchain technology for VCC trading (Dodge, 2018). Proponents of the concept argue that the technology has the potential to improve liquidity while reducing transaction costs (Kotsialou, Kuralbayeva and Laing, 2022). Several of these attempts have come from the "wild west" of Decentralized Finance (DeFi) (Sipthorpe *et al.*, 2022) integrating novel concepts such as NFTs and stablecoins under the moniker of regenerative finance (ReFi). Unfortunately, leading projects have been hit by a slew of scandals related to questionable approaches to the qualities referred to as permanence, leakage, and additionality in the VCM literature.

Additionality refers to the principle that only carbon capture or emission avoidance that would otherwise not have happened by itself can be awarded carbon credits. Leakage refers to the problem of carbon emissions being moved from a carbon capture project area to another area, such as cutting down another forest instead of the one entering the project. Permanence refers to the principle that carbon capture or emission avoidance must effectively last forever to be valid: Capturing carbon (while receiving credits for it) and subsequently releasing it again (without repaying the carbon credits) has no net carbon capture effect.

As a result of questionable practices and doubts about permanence, the leading VCC verification agency Verra suspended verification for tokenized credits traded in DeFi applications in the spring of 2022 (Ledger Insights - blockchain for enterprise, 2022). This decision was made due to potential fraud in the retirement of tokens and the risk of double spending, which questions the overall integrity of the markets. Verra currently verifies almost two-thirds of all VCCs and has recently launched a consultation process to investigate how to create the required integrity for VCCs issued on public chains. Despite these temporary setbacks, it has become increasingly clear that the transparency and tracking capabilities associated with DLT and blockchain provide an interesting opportunity for bootstrapping VCM, including using a shared digital data protocol across the voluntary carbon standards to improve speed, accuracy, and data integrity.

2.3 Regulation

The EU Commission's digital finance agenda in 2020 delivered several groundbreaking regulations in 2022, namely the DLT Pilot Regime regulation no. 2022/858 ('DLTR') coming into effect in 2023, and the Markets in Crypto Assets regulation ('MiCA') coming into force likely in 2024. MiCA and DLTR use the same definition of DLT but approach the topic from different jurisdictions. MiCA will regulate crypto assets that are not securities. Tokenized securities, i.e., digital representations of existing securities, are regulated by the existing securities regulations, namely the Market in Financial Instruments Directive

II and associated regulation (MiFID/MiFIR) as well as the Central Securities Depository Regulation (CSDR), and DLTR. The DLTR provides a potential means to use DLT for trading and settlement systems under those regulations with appropriate exemptions from the regulatory playing field required due to the DLT-based execution. The assessment of suitability takes place in a so-called sandbox, a new regulatory invention, providing a supervisory environment where representatives from the authorities participate in a process of knowledge exchange on novel technology, in exchange for assessment and guidance on eventual licensing and regulatory integration.

3 Method

We utilize the Design Science Research (DSR) methodology to form an iterative process (Gregor and Hevner, 2013) in which new versions of the artefact are designed and then presented to stakeholders for feedback. Each cycle seeks to integrate the increasingly expansive list of artefact requirements emerging throughout the design-search process. The overall project spanned a duration of 14 months, in which the team, including the authors, students providing prototype system implementations, and project partners conceptualized and designed the artefact by implementing variations of the following 6-step process, drawn from the DSR literature: 1) Problem identification, 2) Solution objective, 3) Design, 4) Demonstration, 5) Evaluation and 6) Communication (Peffers *et al.*, 2007). In its final phase, the project involved a group of eight external experts alongside the authors, who participated actively in the design-search process throughout the project's duration (Table 1).

#	**Role in host-organization**	**Role in the design search process**
S1	Special Advisor, Banking Technology Company	Domain expertise, requirements design and evaluation, guidance, support
S2	Partner, regulatory consulting firm	Non-functional requirements design and evaluation
S3	Developer, technology startup	Design, test, implementation, and evaluation of functional requirements
S4	Project lead, Agtech startup	Voluntary carbon markets domain expertise
S5	Capital markets expert, Regulator	Requirements design Multilateral Trade Facility (MTF), artefact evaluation
S6	Fintech expert, Regulator	Domain expertise, guidance, and support
S7	Fintech expert, Regulator	Domain expertise, guidance, and support
S8	Capital markets expert, Regulator	Requirements design CSDR and Regulated Markets (RM), artefact evaluation

Table 1. Stakeholder categories and role in the search process

The project was developed over three distinct phases:

In the first phase, we delivered a conceptual demonstration of the artefact to facilitate discussion while identifying and engaging stakeholders that would help demystify the technological challenges within the regulatory context.

The second phase introduced a Proof of Concept (POC) for the artefact, demonstrating a traditional order book and delivery-versus-payment (DvP) settlement system. The POC was presented to a broader audience in a financial incubator alongside colleagues inside and outside of IS to gauge interest in the concept and collect early feedback from peers. During the second phase of our process, it became clear that new regulation on DLT was to be implemented at the EU level, which would come to present a much clearer regulatory environment for the artefact. These developments led us to consider whether the artefact could be a potential candidate to support the scaling of VCM at the EU level. For this reason, we

sought access to a regulatory sandbox with an EU-based National Competent Authority (NCA), positioning the artefact as a potential accelerator for funding the liquidity gaps and frictions related to the securitization of sustainable funding for SMEs. The search was successful, leading to the development of a pre-production level version of the artefact required for a formal assessment of compliance in collaboration with representatives from the NCA. Due to the restricted scope of the (pilot) DLTR regulation, we re-designed the approach to fit traditional financial instruments, approaching the VCM project funding challenge with a bond structure, iterating away from the initially targeted classical trading of VCC certificates. This development, in turn, changed the focus of the design work from mainly being around the complexities of environmental integrity towards a primary focus on the complexities of financial integrity in a regulated capital market infrastructure.

The third phase introduced an element of intensive regulatory scrutiny, emphasizing and challenging the rationale for existing securities regulation. The intent was to explore reasonable exemptions from existing regulations considering the forthcoming DLTR. By working with representatives directly involved in the negotiation of forthcoming regulation, the team was able to align the artefact for compliance with regulation coming into force in 2023.

The artefact evaluation was conducted ex-ante through expert interviews within the context of the confidential regulatory sandbox (Venable, Pries-Heje and Baskerville, 2016). The evaluation sessions generally took the form of technical demonstrations. As the design-search process progressed, the format was advanced to feature workshop presentations in which the artefact was put to work by demonstrating test scripts. A general model for the design-search process is outlined in figure 1 below.

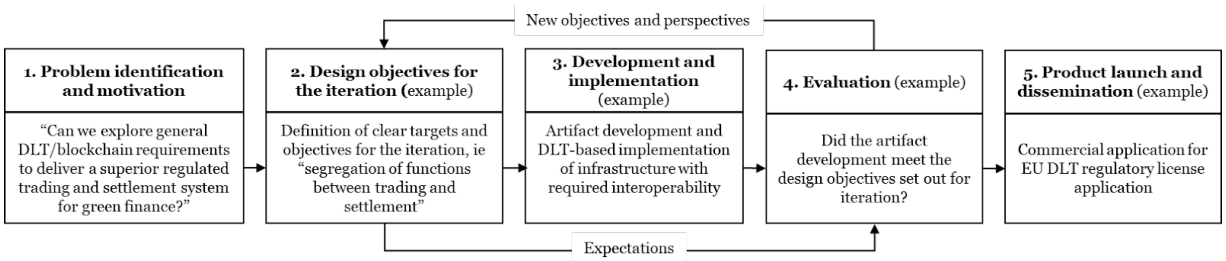

Figure 1. The DSR method applied to the project phases

3.1 Artefact Requirements

Through several iterations, the group of stakeholders delineated a set of requirements for the final iteration of the artefact. In Table 2 we feature a summarized version of the requirements for the latest cycle.

Category	Details
Core Technical Requirements	(1) Manage states of contracts across the securities' lifecycle. (2) Identify and verify that users are authorized for their roles. (3) Maintain ownership of securities (4) Guarantee atomic, consistent, isolated, and durable (ACID) execution of compound transactions, specifically delivery versus payment. (5) Enforce correct attribution and non-repudiability of actions (using digital signatures and cryptographic commitments).

Contextual Requirements and Objectives	(1) Interoperability with external systems. (2) Settlement finality: The determination of a definite time after which the transfer of legal title (ownership) is irrevocable. (3) Support for new financial instruments with high-frequency data dependencies (e.g., carbon emission monitoring data). (4) DLTR compliance with well-reasoned exemptions from existing regulations written for traditional centralized systems. (5) Interoperability with legacy private and central banking as well as private, permissioned, and permissionless DLT/blockchain and other clearing and settlement systems. (6) Support for full access by the financial supervisor/regulator to maximize automated supervision. (7) Full transparency and traceability of underlying verification data throughout carbon credit and advanced instruments' lifecycle. (8) Efficient high-volume trading processing, instantaneous settlement (execution) of trades, real-time monitoring, and advanced market abuse detection (9) Ability to catalyze structured finance by domain-specific language for specifying new instruments and immediately issuing them.

Table 2. Functional Artefact Requirements

4 Artefact Description

The designed artefact is based on the Smart Financial Instrument (SFI) system (Deon Digital, 2023), a smart contract platform developed by Deon Digital with the express purpose of servicing the lifecycle of both regulated and unregulated digital assets and securities. In the present case, the design focuses on the trade and execution of voluntary carbon credits with emphasis on being a regulated tradeable security. Figure 3 displays the high-level architecture and subsystems of the artefact. Their responsibilities (functionality) are listed in Table 3.

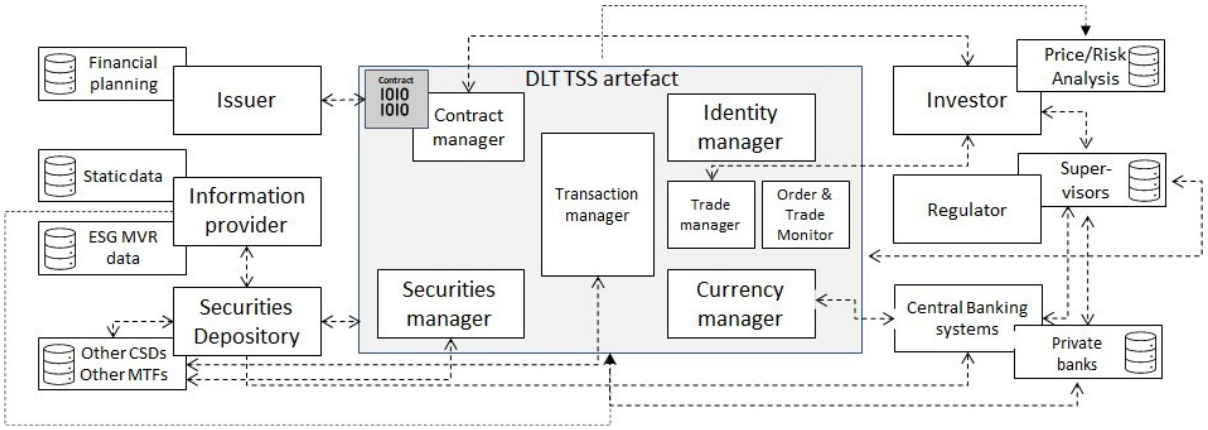

Figure 3: Overview of the artefact architecture and subsystems

The artefact aims at improving the technological shortcomings and reconciliation issues in existing capital market infrastructure by consolidating and formalizing all data, interpretation, and logic necessary to express the nature and lifecycle of the financial instrument.

Identity manager	Maintains up-to-date information about users authorized to access the artefact. This includes regularly updated information sufficient to satisfy KYC/AML/CFT requirements including public keys registered by users for verification of their digitally signed messages.

Contract manager	Receives legally required instrument documents (prospectus and term sheet) and formal contract specification of financial instrument, gets financial instrument approved and rated by designated outside services, launches the instrument so it is live, and checks and processes life-cycle events such as payment instructions and notifications according to formal contract specification of the instrument.
Security manager	Manages ownership of issued instruments reservations (to support transactional exchanges), collateralization (a form of reservation), and finalized transfer of title (full ownership transfer).
Currency manager	Manages ownership of fiat currencies, in particular reservations (to support atomic exchanges, specifically delivery-versus-payment), collateralization, and finalized currency transfers.
Trade manager	Manages matching of buy and sell orders of instruments and their immediate settlement; in particular, reserves currency (buy offer)/instruments (sell offer) when receiving an offer, performs matching of buy and sell offers resulting in a spot exchange contract (trade), and settles the trade in real time via atomic transfers in the security and currency managers.
Transaction manager	Stateless service that guarantees logical atomicity, all-or-nothing execution of a set of state changes in multiple state managers, e.g. to guarantee atomic delivery versus payment.
Order and trade monitor	Configurable, stateless service that subscribes to the trade manager to receive both authenticated orders and settled trades and performs both real-time and ex-post analysis of orders and trades. It automatically identifies single or connected groups of orders and trades as suspicious based on configurable specifications and market abuse detection techniques.

Table 3. Overview of architecture components.

4.1 State managers

The first five of the subsystems in Table 3 are state managers. In general, a state manager is characterized by a mathematical function f, that deterministically computes its current state *s* from its current log *l* of previously validated events; that is, $s = f(l)$. If $l' = l*e$ (l extended with a new event e), then the state is updated to $s' = f(l')$ using an efficient incremental-update version of *f*. In particular, the unique correct state of a state manager can be reconstructed after a crash failure and checked for correctness at any time by an external service from the mathematical definition of *f* and the tamper-evident ledger of previously validated events. A state manager provides an API for submitting events for validation, querying the current state, subscribing to new validated events and supporting 2-phase commit for synchronized commitment of multiple events and their storage on multiple ledgers.

4.1.1 Resource managers

The currency and security managers are examples of resource managers. A resource manager maintains ownership and processes transfers of any number of resource types (currencies, assets, tokens, etc). They guarantee that the total amount of resources in the system is constant and that transfers can be performed in any order that does not violate their owners' credit limits. In particular, this means that the question of enforcing zero credit limits, corresponding to balances of ordinary users not being allowed to become negative, is the only ``real'' consensus problem requiring more than point-to-point communication between authenticated agents (Henglein, 2018).

The security manager maintains the balance of ownership of the securities it manages. The function *f* in this case, is the summing of the validated transfers (viewed as a suitable mathematical structure) in the ledger. The balance is used in validating submitted transfer instructions: a transfer that would result in a

negative balance is rejected by the security manager.

The currency manager maintains fiat currency accounts if its operator is licensed to do so. Alternatively, it is implemented as a proxy service to a banking or e-money institute API where the accounts are held. Likewise, it can also be implemented as a proxy service for blockchain systems if payments are to be made in stablecoins.

4.1.2 Contract managers

A contract manager maintains the authoritative state of a set of issued financial instruments that are still live. It is a state machine that maintains the current state *c* of a financial instrument identified by International Securities Identification Number (ISIN) number *I* according to the instrument's formal contract specification in the domain specific language CSL (CSL Platform Documentation). A contract manager receives a digitally signed event *e,* for example a coupon payment instruction, for *c,* one of the instruments it is in charge of, from a client and checks whether *e* matches *c* in the sense of being an admissible action according to the contract specification. After validation by other managers, if any (for example, the currency manager executing/validating the payment instruction), it logs *e* associated with *l* in its ledger and informs subscribers (clients) of this event having happened. It also updates the state of *I* from *s*, before the coupon payment, to its new residual state *s'*, the state of *I* after the coupon payment. Clients can query the authoritative state of *I* and may submit bids and offers for *I* tied to a particular state to ensure that an offer to buy *I* in the state before a coupon payment is not matched with an offer to sell *I* after coupon payment.

Contract managers do not require synchronization amongst themselves since the order of events for different contracts is *a priori* irrelevant; they are only synchronized via a resource manager in case of a resource transfer. For example, a notification by the issuer to execute a prepayment clause of a bond requires no synchronization with any other events and thus no communication with other contract or resource managers.

4.2 Transaction managers and network activity monitors

A transaction manager is an essentially stateless service that effects atomic transactions, that is all-or-nothing updates of multiple state managers using a customized 2-phase distributed commit protocol.

They only require local state during a transaction, which does not need to be retained once a transaction is concluded. Consequently, any number of independent network nodes, each running an independent transaction manager, can be employed for scalability.

An order and trade monitor monitors suspicious trading activities as required by regulation. Any such activity is then filtered by tool-supported human analysis for eventual regulatory reporting to the supervisory authority. Additionally, it provides an API for the supervisory authority to submit and execute queries/programs of their own choosing on the order and trade data that are securely and authoritatively logged in the trade manager ledger. Multiple monitors operating on independent network nodes, each monitoring a distinct set of instruments, can be employed for scalability.

This demonstrates the feasibility of a modularized internal market surveillance function that operates by subscribing to the trade manager's received and validated orders as well as (settled) trades. This facilitates 'embedded supervision,' where the NCA is authorized to install their own fully automated trade supervision modules as a regulatory observer rather than engaging in lengthy and mutually costly email interchanges requesting certain data in (imprecise) natural language (Axelsen, Jensen and Ross, 2022).

4.3 Distributed Systems Architecture

The artefact employs a two-level distributed systems architecture. At the top level it consists of independent state managers with distinct functionalities, each of which has its own thread of control and maintains its own cryptographically secured append-only digital ledger. The state managers are coordinated by transaction managers employing a distributed 2-phase commit protocol to ensure atomic execution of multiple actions. At the bottom level, each of these subsystems is implemented by a small set of nodes employing an active replication protocol for crash failure resistance.

In a simplified implementation there are no secondaries in the bottom layer: Each state manager is implemented as a single node on a secure network whose ledger is continuously written to local disk storage and, in encrypted form, to an off-site secure storage facility. This constitutes a permissioned DLT-based system: All messages are digitally signed where every user and node operator is identifiable as a legal person by the identity manager. In particular, the digital signature in a message, for example a payment instruction, provides non-repudiable evidence that (somebody having access to the private keys of) a specific, identified legal entity has authored the message.

The artefact is functionally sharded: It has no global blockchain that sequences all recorded events whether doing so is logically actually required. The conceptually collective state of the ledgers *in toto* comprises the set of all validated state messages of all state managers. They are synchronized across state managers to the degree logically necessary.

Note that this is different from both mainframe systems and conventional blockchain systems, whether permissioned or non-permissioned, where arriving messages are sorted into a single linear stream of events prior to processing them, irrespective of whether such ordering is needed in an application. Consensus on a total order of events arriving at the network nodes of a distributed system, however, is an inherently severe performance bottleneck for any distributed system, including both non-permissioned and permissioned blockchain systems. It is ultimately even unsolvable in deterministic asynchronous distributed systems with just one node that can fail (Fischer, Lynch and Paterson, 1985), which expresses itself as the ``trilemma'' problem in blockchain systems.

The relatively easy programming problem of writing reactive single-threaded code in an Ethereum-style blockchain system is thus bought at the great expense of solving an inherently hard problem at each step: distributed consensus by all nodes on a specific order of a block of events. In contrast, the artefact does not build a global blockchain or any other data structure implementing a single linear sequence of events. Its `functional' sharding yields scalability: Ownership of securities and money is managed in independent subsystems whose execution is not fine-grained synchronized. Instead, the artefact's transaction manager synchronizes updates on multiple state managers only when needed.

4.4 VCC Instrument Execution

An issuer can issue a bond whose life-cycle actions include not only payments to the investors but also information events provided by designated verification assurance and calculation agents. This is described by the following state changes, visualized as a UML sequence diagram in figure 4.

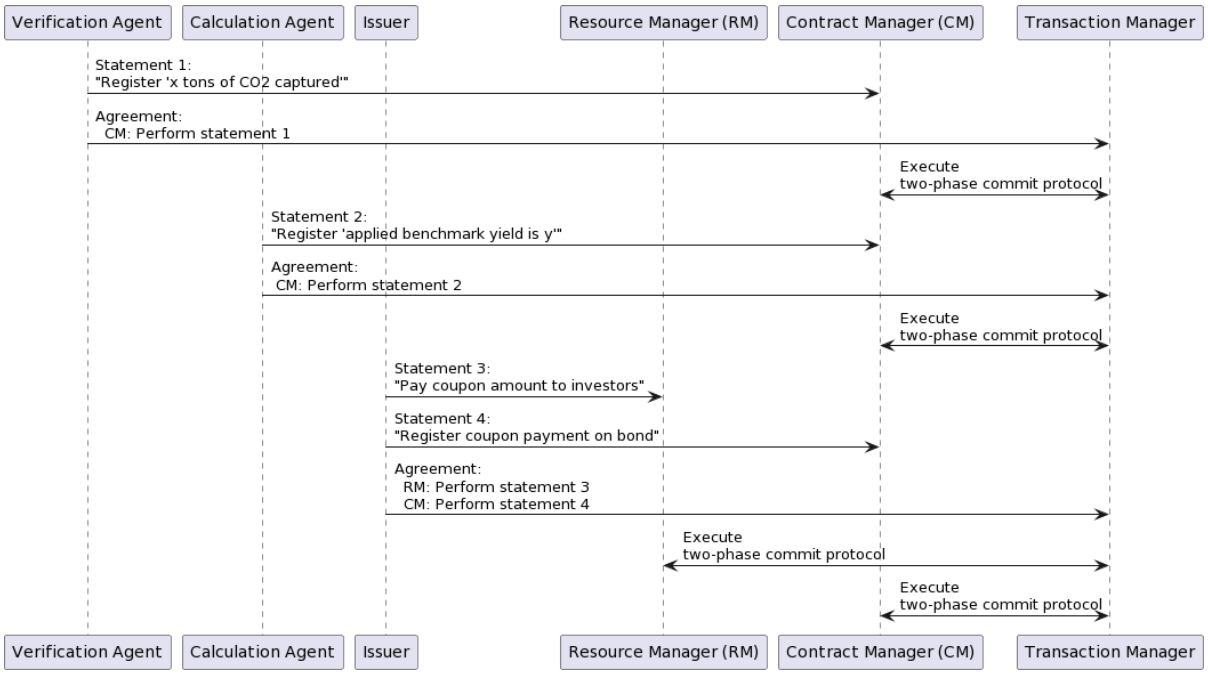

Figure 4. Sequence diagram for bond with coupon payments dependent on data from independent agents

There are four statements executed among 6 participants (nodes): (1) 'Verification Agent' V verifies to 'Contract Manager' CM that X ton of CO2 has been captured within the scope of the given green bond. V also confirms to 'Transaction Manager' TM to execute this statement as a two-phase commit. (2) 'Calculation Agent' C confirms to CM to register the yield as Y, while also instructing TM to perform this statement, again, as one two-phase commit. (3) 'Issuer' I then instruct 'Resource Manager' RM to pay this coupon to investors, and (4) CM to register that coupon payment on the bond. Once confirmed, the TM executes those instructions, again with a two-phase commit.

5 Results and Evaluation

The final evaluation was conducted with the full panel of stakeholders representing industry and regulators and uncovered several interesting perspectives on the feasibility of the artefact. First, we examine the core technical requirements posed to the artefact (Table 4).

#	Requirement	Evaluation summary
1	Manage states of contracts	The artefact demonstrates both conceptually and in regulatory testing how states of contracts are managed during all steps of a financial instrument's life cycle according to its formal contract specification.
2	Identify and verify users	The artefact demonstrates how identities are established, verified, and authorized for their role.
3	Maintain ownership	The artefact demonstrates how ownership of securities, monies, and other assets are safely and transparently maintained using resource managers that guarantee that resources can neither be digitally lost nor duplicated.
4	Guaranteed transactionality	The artefact guarantees atomic execution of compound transactions across internal and external subsystems, in particular delivery versus payment.
5	Non-repudiability	The artefact maintains a tamper-evident, securely stored ledger of the authoritative sequence of events, each non-repudiably digitally signed by legally identified agents.

Table 4. Evaluation of core technical requirements.

5.1 Throughput, Finality, Interoperability, and Settlement

The attainable throughput for the artefact was tested with a hand-coded complex financial instrument with several life-cycle activities to evaluate its throughput potential. Results demonstrated throughput between 200,000-13,000,000 events per second on a single standard cloud-hosted server, depending on how the digital signature checking was implemented and how often checking signatures was needed (Petersen, et al., 2022). The events included both price observations (predominantly) and payments. Compared with the Nasdaq Historical TotalView-ITCH requirements, which contains all events in every instrument traded on the Nasdaq exchange, a standard limit order book structured exchange handles up to 200,000 messages per second. A conservative fully distributed implementation of the artefact can be expected to reach more than 1,000,000 messages per second even with full individual digital signature checking since total-event-order consensus across different financial instruments being life-cycled and traded is neither needed nor implemented.

In a theoretical near-perfect implementation with high-performance computing infrastructure distributed across thousands of servers, the artefact may even scale beyond these numbers. Yet, high processing throughput does not necessarily translate into the ability to validate transactions fast in practice, as there are several real-world drivers of potential latency, especially in identity management if authentication involves external services and settlement of payment instructions involving central or commercial bank money.

A key requirement for securities settlement systems, such as T2S at the European Central Bank, is to comply with the EU settlement finality directive, which stipulates that there be a well-defined point in time after which transfers are irrevocable to secure the rights of creditors after a transferor's default. To date, there are concerns about the extent to which blockchain systems employing probabilistic consensus meet the 'deterministic eligibility criteria' (ECB Advisory Groups on Market Infrastructures for Securities and Collateral and for Payments, 2021) for Delivery vs. Payment (DvP).

While IS scholars generally accept blockchain finality as sufficient for verifying the integrity of a transaction once a sufficient number of blocks have been verified (Nærland and Müller-bloch, 2017) concerned voices at regulatory institutions do not approve of probabilistic settlement finality. The artefact provides deterministic finality of security transfers via its own security manager and irrevocability of payment instructions issued to the banking system. Its transaction manager can even act as a real-time bridge with deterministic finality between multiple external systems including blockchain systems if these provide support for reservations (precommit) and subsequently releasing (commit) or returning (abort) reserved resources deterministically. The former is easily programmable as smart contracts; the latter, however, is problematic for Ethereum-style permissionless systems employing probabilistic consensus, which is either slow (takes more than a couple of seconds) or risks retraction (previously confirmed transfers are implicitly revoked when a longer chain without it appears) or both. While the artefact is capable of interoperating with permissionless blockchain systems via its transaction manager, its finality and regulatory acceptance depends on the finality of participating systems.

In the words of DLTR, the 'Union financial services legislation was not designed with distributed ledger technology and crypto-assets in mind and contains provisions that potentially preclude or limit the use of distributed ledger technology in the issuance, trading, and settlement of crypto-assets that qualify as financial instruments.' DLTR defines a 'distributed ledger' as an information repository maintaining records of transactions synchronized between network nodes using a consensus mechanism. Curiously, DLTR does not explicitly require tamper-evident or, stronger yet, tamper-proof recording, which is usually taken to be a core characteristic of blockchain/DLT systems (Henglein, 2018, Kolb *et al.*, 2020).

The artefact adequately meets the definition set out in the DLTR package: Instruments are formally specified, and the artefact maintains their definitive, unambiguous current state throughout their lifecycle. Since settlement is instantaneous, there is no settlement risk, except for any latency added in the payment settlement leg if that is done in fiat currencies such as EUR or USD through the banking system. In particular, no central counterparty is required to protect trading partners from their counterparties' inability or unwillingness to deliver on their part of the bargain. All information can be provided on equal terms to all users. Bids, offers, and trades are digitally signed, processed, matched, settled, and securely stored in seconds ('T+0') rather than days ('T+2'), the current standard in traditional capital market infrastructure. The current and all previous states and all events relevant to an instrument can be inspected and independently verified based on the contract manager's immutable ledger and the instrument's formal specification. The artefact provides crash-fault tolerance, and any state manager that does not implement its semantics correctly is discoverable and is treated as failed by all other (non-Byzantine) managers.

In the light of these features, the artefact may qualify for exemptions to regulatory requirements disallowing direct retail participation, as there is no settlement risk and hence no direct insolvency risk, and the artefact does not require the obligatory traditional custody and servicing of assets by banks and brokers.

6 Discussion

Voluntary carbon markets (VCMs) are currently maintained in a way that separates the registry, project documentation, carbon credit documentation, and trading contract. When a registry issues a Verified Carbon Certificate (VCC) the purchaser must trust that the documentation has been properly examined in accordance with the measurement, verification, and reporting (MVR) protocol. The issuer pays the registry, and an end user of the VCC must trust that this process is accurate and free of any integrity issues as in traditional capital markets, where an issuer pays a rating agency in a similar manner. Furthermore, the prevailing trading contracts of current VCMs refer to a carbon certificate, which is essentially a data

record on the registry and must be changed to the new owner or retired manually through a web interface (such as Verra), leading to compartmentalized and isolated information.

The artefact presented here is built on a fully digital representation of the financial instrument with all transactions and evidence recorded immutably, and to the extent this recording includes all previous records, the artefact will enable full transparency of the underlying certificates of the VCM. By creating a one-stop shop with the functionality outlined for the presented artefact, a purchaser has access to all up-to-date information in one place. The platform functionality may also allow an issuer to issue compliant financial instruments that pool credits from similar activities and thus inherently diversify the source of credits and their risks. Traditional VCM markets cannot include such information since the existing capital markets rely on old messaging technology supporting only payments (SWIFT). So, although the artefact design presents significant improvement to the market infrastructure, enabling full documentation verification, protocol compliance, and transparent credit pooling, there is still a level of fragmentation as long as environmental and financial integrity standards are not aligned. As pointed out by TSVCM the long-term solution is integration, which will only happen, when Article 6 of the Paris Agreement is fully completed.

In this paper, we report on the design of an artefact under a new regulatory regime with a group of industrial and regulatory stakeholders. The project was designed to address the research question: '*To which extent can distributed ledger technology (DLT) facilitate efficient issuance, trading and settlement of regulated financial instruments (green bonds) to finance carbon capture based on verified and traceable carbon credits in voluntary carbon markets?'*

The final design of the artefact demonstrates the feasibility of a trading and settlement system for green bonds by satisfying the core technical requirements posed for traditional trading and settlement systems with DLT and formalized contracts for end-to-end digitalization. In addition, the use of DLT introduces several appealing features for the trade and settlement of securities, such as atomic settlement with pre-funded trades, as well as reducing counterparty and liquidity risk in existing T+2 settlement systems, a point frequently raised in the literature (Jensen and Ross, 2021). Compared to conventional blockchain systems, both permissionless and permissioned, that implement a replicated state machine and enforce global consensus amongst all nodes on a particular order of events, the artefact exploits the lack of need for synchronizing *all* events with each other. Synchronizing all events is a built-in bottleneck in blockchain systems, which are required to achieve consensus on a *single* global chain (total order) of all transactions.

Here we have only addressed the issue of VCM infrastructure. To meet the full infrastructure capabilities outlined by TSVCM, the artefact should support the VCC certification process throughout the instrument's lifecycle. The artefact will need to be complemented with advanced analytics add-ons, which can rely on the verified state managers' logs a their single, authenticated source of truth without having to be built into the system itself. Its security registry needs to be implemented as a meta-registry, that is as a proxy service aggregating the collection of individual source registries managed by carbon certificate verification agencies. While the artefact meets the technical requirements identified in the design process, the challenges of integrating DLT-based solutions into the existing financial IT infrastructure remain pertinent. Further, it may also be argued that some regulatory objections to DLT-based solutions in finance are based on technically unwarranted preconceptions and traditions. Addressing these objections should be considered a natural part of the gradual integration of radically innovative technologies (Beck and Müller-Bloch, 2017). As such, it is incumbent upon IS scholars and practitioners to motivate exemptions from traditional securities regulation by showcasing how DLT-based solutions can either reduce frictions in existing markets or enable the flow of funds to otherwise underserved constituents of the financial system. In this paper, we argue that introducing a regulated DLT-based solution in the VCM may incentivize the issuance of VCC-backed securities and promote environmentally sustainable practices in agriculture and beyond, provided that the on-the-ground certification challenges can be overcome.

Summarizing the benefits, challenges, consequences, and mitigation practices required for the adoption of DLT TSS for a Green Bond market, DLT can reduce friction in the lifecycle of financial instruments by executing processes normally requiring multiple service providers within a single component-based distributed architecture.

The transparency of blockchain and DLT-based systems and their novel technology-specific capabilities may be perceived as radical innovations by traditional supervisors, who are used to the standard organization and centralized IT architecture implicitly assumed in current financial regulation. They may question the rationale for allowing distributed systems, mathematically guaranteed transparency, end-to-end digitalization and providing investors with direct control of their assets into financial markets. By gradually designing DLT-based systems to prove value to regulators as guardians of society at large in terms of increased investor protection, market integrity, transparency, and efficiency as well as financial stability, DLT should gain traction considering its superior functionality, transparency and security. But while DLT may be part of the answer, agreements on carbon integrity and financial market integrity principles are required to fully develop a trustworthy sustainable capital market. A secure digital currency, whether central-bank digital currency or just e-money guaranteed to be default-free (by being kept in a central bank) will enable contract-backed ('programmable') digital money (Henglein, 2022) with legally final delivery-versus-payment settlement within seconds of a trade and thus elimination of counterparty and settlement failure risk, but alignment of ESG taxonomies, securitization rulebook and settlement rules may also be required for the creation of a fully regulated, efficient secondary DLT-based capital market for VCM.

7 Conclusion

In this paper, we have investigated the general blockchain/DLT requirements given recent regulatory developments. We demonstrate how an artefact can be licensed as a fully compliant DLT-based trading and settlement system (DLT TSS) with positive network effects and the ability to deliver full market integrity, including motivations for exemptions to existing securities regulation according to the recent EU DLT Pilot Regime. DLT applications for carbon markets present significant benefit potential by providing transparency and traceability. However, the current markets lack integrity, and this lack of integrity is being exploited in permissionless blockchains to the extent that global verification bodies have suspended verification of the same. DLT with its associated technical and organizational innovations appear well-suited to deliver better solutions to capital markets by enabling a higher level of transparency, security, and legal certainty at substantially lower risk and cost. As the regulatory world cracks the door open to new technologies for improving security, transparency, investor protection, costs, and market efficiencies rather than instinctively associating them with anarcho-libertarian motives and as DLTR use cases present themselves as viable alternatives to legacy structures in the trading and settlement of securities, we believe the legacy capital market infrastructures will be challenged. The risks associated with this change are manageable, and the benefits appear attractive.

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DLT Compliance Reporting

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Abstract. Today, local financial institutions are responsible for submitting compliance reporting data to the supervisory authorities. This is commonly referred to as the 'push model'. The increasing complexity of reporting obligations often results in delayed reporting which delivers a fragmented and incomplete macroeconomic overview of the financial sector. Working with a group of nine representatives from industry and regulatory authorities, we employ the design science research methodology (DSR) in the design of an artefact, enabling the automated collection and enrichment of transactional data from DLT ledgers. Our findings demonstrate how the adoption of DLT in the financial sector will facilitate the automation of compliance reporting through a 'pull-model', in which regulators can access compliance data in near real-time and stage aggregate macroeconomic risk exposures for the eurozone. The findings contribute practical insights to the discourse on design-driven research on DLT and blockchain technology.
Keywords: DLT, Blockchain, Compliance, Reporting, Automation.

1 Introduction

All public and private companies operating in developed economies are subject to some level of regulatory compliance, either in the business reporting context, or through requirements for financial accounting. Due to the systemic importance of large financial institutions in the global economy, banks are amongst the most heavily regulated organizations and are subject to strict compliance reporting requirements, ranging from data gathered for the compilation of macroeconomic statistics all the way down to microeconomic supervisory needs. Since the financial crisis in 2008, regulatory reporting requirements within the EU has grown by more than 40 pieces of legislation. This has generated a significant number of new and granular reporting requirements, imposing additional pressure on both authorities' and financial institutions' reporting systems [1].

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Reporting obligations are specified at the global level through supranational bodies such as the Bank for International Settlement (BIS) and the Basel Committee on Banking Supervision (BCBS) and transposed to the European level in a variety of legal frameworks. Frameworks span from the macro-level mandated by the European System of Central Banks' Integrated Reporting Framework, down to the micro-level supervision tasks mandated by EU directives and regulations that are interpreted by the European Banking Authority (EBA). These international bodies mandate prudential risk reporting through the format *Implementing Technical Standards* (ITS), requiring local supervisors to collect aggregated risk data from banks. ITS risk reporting comprises more than 500 complex obligations and incorporates thousands of tables containing tens of thousands of data fields. The combination of these fields is used to produce different kinds of reports, submitted to regulators on a monthly, quarterly, semi-annual, or annual basis. The annual cost of ITS risk reporting is estimated at up to €12bn annually for the population of about 5,000 banks in the European Economic Area (EEA), equivalent to approximately one third of banks' total cost of compliance (Eba 2021; EBA 2021a; European Commission 2021). In practice, it is the banks that collect data from their internal systems, map this operational data to the data elements needed to populate regulatory reports (so-called 'input data'), transforming reporting data based on reporting instructions and subsequently submitting reports to the competent authorities. Because banks are responsible for submitting this data themselves, this model is known as the *push model*. European banks have made moderate progress in improving data management in the *push model* motivated by strict obligations enforced since 2013. Yet, material challenges remain unsolved across markets, mainly due to a lack of alignment between new IT solutions and legacy systems [5]. These technical challenges are exacerbated by an increasingly complex regulatory environment in which regulators frequently introduce changes to reporting frameworks and require multiple different data models for different ITS reporting requirements. As a result, banks often take up to 90 days to produce compliance reports, even under stressed conditions. This latency can have highly detrimental implications for the regulators ability to understand systemic and structural risks to the European economies.

Working with a group of nine stakeholders representing perspectives from banking, central banking, supervisory authorities, and banking regulators within the European context, we examine how the DLT-based solutions emerging between institutions and governmental bodies could reduce the reporting burden, by facilitating a so-called *pull-model* for compliance data, enabling regulatory bodies to *pull* any the necessary data as it is produced in real time. We address the research question: *To what extent could the adoption of DLT based solutions optimize ITS compliance reporting for banks and organizations in the EEA?* We present ongoing work towards the design of a DLT agnostic artefact designed to collect and enrich transaction data with ITS reporting compliance data.

While the discourse on the efficacy and potential of DLT in financial processes has grown at a tremendous pace in recent years, little has been said about the implications the adoption of this technology will have for the topic of compliance reporting. By employing the design science research (DSR) methodology in the design and evaluation of a conceptual artefact with this group of stakeholders at international and governmental institutions, we seek to contribute new practical and actionable insights on the topic of compliance to the growing DLT and blockchain discourse in the IS literature and beyond.

The structure of the rest this article is as follows. The compliance reporting issues regarding DLT are described in Section 2. The research approach used is presented in Section 3. Proposed artefacts are described in Section 4. Validity of the artifacts is addressed in Section 5. Section 6 and Section 7 are comprising discussion and brief conclusion respectively.

2 Compliance Reporting and Distributed Ledger Technology (DLT)

In the 'push-model' for compliance reporting local banks push data to their local authorities, which subsequently consolidate banking group reports and push these to the supranational level (Figure

1). The national competent authorities (NCA) for supervision, resolution (NRA) and central banking (NCB) are subsequently responsible for pushing the data forward to the respective targets at the European level – the European Banking Authority (EBA), the European Central Bank (ECB) and the Single Resolution Board (SRB). The resolution authorities are part of the flow, as they cooperate with the other institutions, and the same reporting obligations are used when a bank is failing to assess how to resolve it.

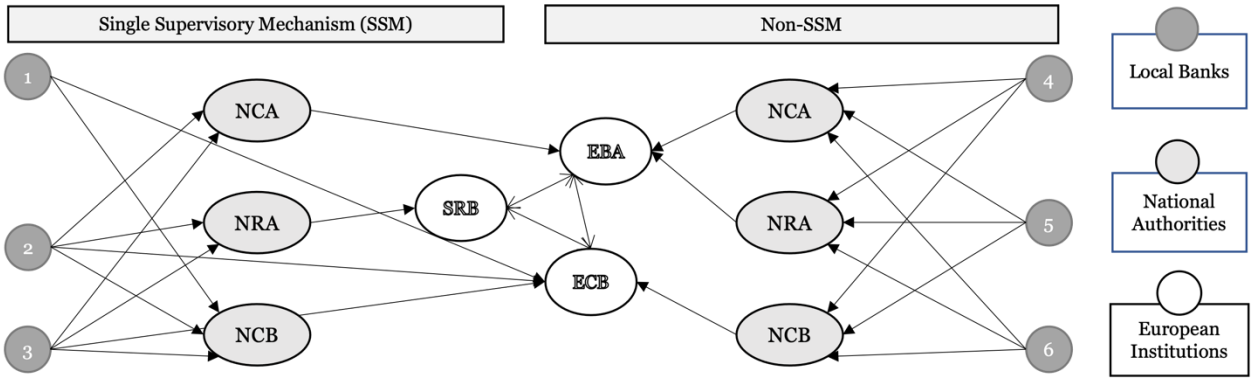

Figure 1. Illustration of the Current 3-tier push-model for ITS compliance reporting

Practically, reporting is initiated by the local banks, that submit a pre-defined XML-report to the local authorities, often through a portal jointly operated by the NCB and NCA. As the reporting obligations include sensitive data related to privacy, banking regulatory secrecy and competitive status, data is masked for analytical purposes and further truncated such that sensitive data is not easily identifiable. The data is subsequently processed to create supervisory or statistical reporting, which is pushed to the European authority level as stipulated by the supranational bodies policy mandates. Traditionally, data security is managed via identity and access management controls, network segmentation, strong communication protocols supported by firewalls, data segregation, monitoring, and process controls to avoid leakage and abuse. Figure 2 shows the steps of the compliance reporting process [6].

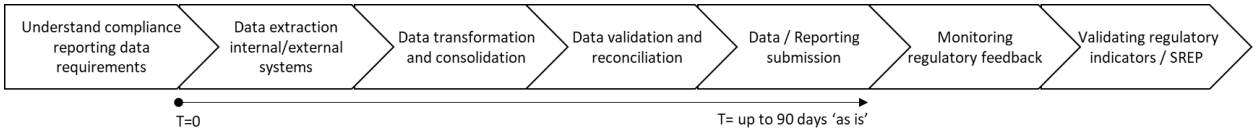

Figure 2. Compliance reporting process

Distributed Ledger Technology (DLT) denotes a distributed transactional database that is replicated across multiple peers in a network with a shared communication protocol, facilitating a tamper-proof record of transactions [7], [8]. In recent years, scholars have demonstrated how DLT may (a) enable atomic settlement of transactions [9], [10] and automate the execution of OTC derivatives [11]; (b) increase resiliency (no 'single point of failure') while reducing ambiguity in transactions by providing full disclosure of a 'single truth' for all network participants [12]; (c) simplify and automate collection, sharing, reconciliation and reporting processes for sensitive data [13] while increasing transparency and reducing operational risk [14]; and (d) promote general data protection regulation (GDPR) compliance [15].

DLT has been applied in a vast variety of use cases within and beyond the financial sector, including trading of carbon credit (green bonds) [16] in emerging economies [17] in shipping logistics and beyond [18]. While the notion of *permissionless* blockchain technology is generally contained within the DLT classification, as a variation of the concept, in recent years the literature has differentiate the terminology. To this end, scholars now tend to use the term blockchain technology in situations where activities are conducted between unregulated counterparties. This

may include the concept of ‘decentralized finance’ [19] or ‘decentralized autonomous organizations’ (DAO) [20] in which stakeholders collaborate on open-source projects through decentralized coordination [21]. DLT, on the other hand, is used primarily to indicate use cases in which stakeholders are regulated and are subject to strict rules and obligations. These might include cases in which innovation is proposed in a traditional financial setting, as for the work described in this article.

While the open-source approach associated with public blockchains was initially opposed by the prevailing thinking in traditional financial services, major institutions on all continents are now experimenting with the technology in view of its attractive characteristics. As a result, banks now represent more than 30 pct of DLT use cases [22] in-line with innovation in ‘machine-readable regulation’ [23]. Because of these unique features, the use of DLT has been studied extensively in central banking, mainly on the topic of Central Bank Digital Currencies (CBDC), specifically towards payments clearing and settlement, market compliance, asset ownership, audit trail [24] and embedded supervision and automation with smart contracts.

The traceability of DLT may reduce the risk of fraud by designing a legal framework for automating the connection of real-world identities to cryptographic identities in a common database for consumer protection, KYC rules, AML, CFT regulations tax, capital and credit management [25]. This could effectively remove duplication efforts in identification across nodes and enable encrypted sharing and feedback loops between entities and regulators. Yet, traceability must be weighed against privacy and the need to keep certain information confidential. On a blockchain, where all information in the ledger is typically observed by all participants, transparency might also result in loss of privacy, confidentiality or competition issues, especially when applied to financial services. This may introduce discrepancies with data protection and applicable privacy laws, including in the EU, the GDPR, and other applicable regulations, such as local banking secrecy laws.

3 Methodology and Artefact Requirements

We apply the design science research (DSR) method in an iterative design, development and evaluation process [26]. DSR is a research methodology widely used within the Information Systems (IS) field, but its principles has been applied in various disciplines such as engineering, education, healthcare, business, and more. It involves the creation and evaluation of "artifacts" designed to solve complex, real-world problems. Artifacts here refer to constructs, models, methods, and instantiations designed to meet specified requirements. To this end, DSR is both a problem-solving and knowledge generation process. It contributes to theory by providing a novel solution to a problem, extending our understanding of the problem space and solution design, as well as providing rigorous evaluations of these solutions.

The artefact is conceptualized through a multiple successive cycles of demonstrations and feedback-sessions with stakeholders leading into the subsequent cycles [27]. We conduct evaluation processes ex-ante, through expert interviews [28] in which we attach specific emphasis on mitigation of development risk through continuous feedback [29].

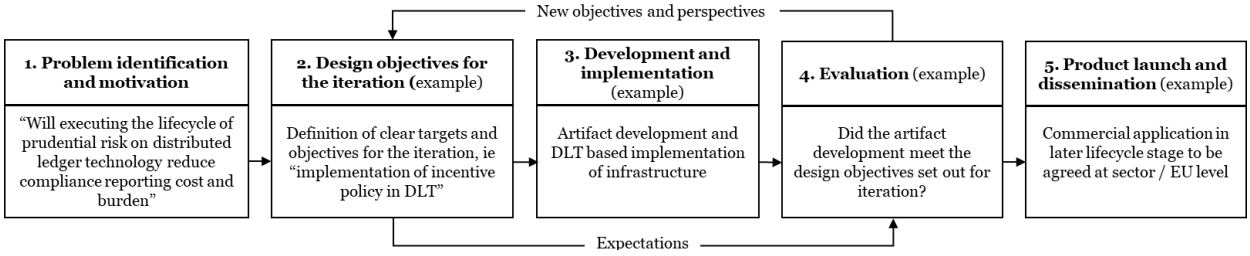

Figure 3. DSR framework applied to the project’s search process

Our search process was initiated by a 2-day workshop with the initiating stakeholders, in which we identified and motivated the problem to define the key objectives for the artefact. We subsequently conducted a series of individual and group-based interviews with the stakeholders[†], starting in January 2022. The list of stakeholders and their role(s) in the research process are shown in Table 1.

Table 1. Stakeholder categories and role(s) in the research process

	Role in host-organization	**Role in the research process**
S1	CEO, Banking Technology Company	Domain expertise
S2	Deputy Director General, Supervisory authority	Domain expertise, guidance, and support
S3	Digital Expert, Central Bank	Non-technical evaluation of artefact requirements
S4	Head of Innovation, Central Bank	Non-technical evaluation of artefact requirements
S5	Solution Architect, Central Bank	Technical evaluation of artefact requirements
S6	Supervisory Data Team, Supervisory authority	Reporting burden expertise, evaluation of artefact
S7	Head of Reporting, Regulator	Reporting burden expertise, evaluation of artefact
S8	Director, Regulator	Domain expertise, guidance and support
S9	Head of Blockchain, Trading platform	Evaluation of artefact, guidance

The interview format was open-ended and semi-structured and they typically lasted up to 60 minutes per session. Early in the research process, we conducted stakeholder interviews without prior briefing. In the evaluation phase, we briefed stakeholders prior to the interviews, to keep them up to date on the latest iteration of the artefact design. The interviews were conducted ensuring proper consent and confidentiality, using a tailored interview guide [30]. The interviews where structured to emphasize the realignment on the problem motivation, the iterative evaluation of the artefact design, and requirements for subsequent rounds.

We conducted 840 minutes of stakeholder interviews, generating 149 pages of interview notes. The project is open-ended, and all stakeholders agreed to commit time to participate in evaluations for subsequent iterations of the artefact. While our data sampling strategy was initially aligned with our preconceptions about the use of DLT for compliance reporting, we sought to remain open to new theoretical insights in the research process [31]. Through the interviews, it became clear how stakeholder incentives amplified the existing complexity in the identification and motivation of a narrow problem scope, which lead to an emphasis on the need for flexibility and modularity in the artefact design.

In parallel, we iterated on the issued experienced by reporting entities and their possible root causes. Leveraging the interviews and the global and regional large-scale studies conducted through the banking and supervision partners, this mixed approach made it clear how a lack of incentives may exacerbate the complexity of the problem. This led us to further conceptualize the need for flexibility and incentive mechanisms for the artefact. Through these focused interactions we refined the search process and literature comparison to foster a better understanding of how DLT might help reduce the compliance reporting burden, and what governance trade-offs the adoption of DLT might introduce.

This process led to the elicitation of the artefact requirements. We summarized these requirements (Table 2) grouping them into three general categories [32].

[†] To preserve the anonymity of the authors, the organizations in which the stakeholders are employed have been described superficially in this submission.

Table 2. Artefact requirements for the presented iteration

	Requirement's title	Description
Data	Data sources and interoperability	The artefact must demonstrate the reporting flow from reporters to authorities using a *pull-model* system that is interoperable with multiple other non-integrated data sources (synthetic reporting data).
	MRER (machine readable regulation)	The system must create machine-executable versions of reporting requirements, expressed in a logical and consistent sequence useable by deterministic computing systems.
Rights	Security and Privacy	The system must ensure compliance with data privacy and confidentiality regulation, while also allowing read/write privileges to the appointed authorities as per delegated governance mandates.
	Delegation	Risk and obligations must be delegated to system participants, implying the use of one entry point, a simple legally enforceable framework, with role-based access and identity management.
Accountability	Data *pull* vs *push*	The system must allow the public authorities to pull the required information directly via the reporting agents for real-time analysis, supervisory review and evaluation and statistical modeling.
	Relevance and Incentives	The system must feature strong incentivizes for participation, with "opt-in" mechanisms allowing phased entry for participating banks by reducing cost-of-compliance for local banks and institutions.

4 Artefact Description

This early iteration of the artefact design comprises a general database architecture in which transaction events are parsed and enriched with ITS data and are subsequently stored for modular ITS report aggregation. The enriched data comprising the fields that make up ITS reports can be *pulled* by regulators from a data warehouse as data is consumed from the DLT environment and enriched, in near real-time. The architecture is rooted in an active node for the targeted DLT environment. The DLT node is simultaneously running an on-chain event API that listens to native transaction and smart contract events. The on-chain event API is consumed by the 'Composer', a program which observes state changes on the targeted network and records events associated with addresses registered with participating institutions. The Composer queries a database referred to as the 'ITS Datastore' to enrich the on-chain event data with ITS data and subsequently stores the fields in a data warehouse (Figure 4). The ITS datastore contains relevant information on the institutions operating on the DLT solution, which is used by the Composer in the calculation of leverage and capital ratios, liquidity requirements, credit exposures, trading flows, and more. By consuming on-chain events, the Composer maintains logs of activities on the ledger related to participating institutions, which is used in providing a picture of the bank's operational status.

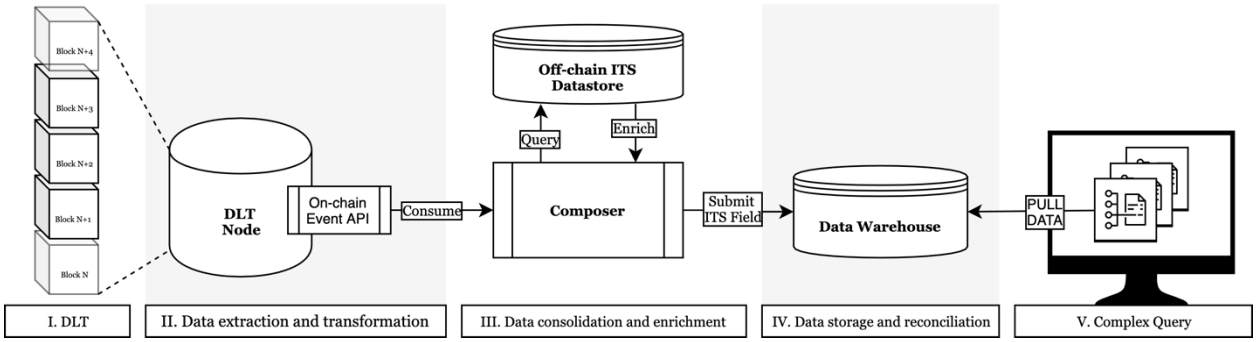

Figure 4. Artefact illustration – DLT system of systems for compliance reporting

While the ITS datastore does not yet contain adequate information to enrich and submit the full scope of ITS reports at this stage in the research process, early implementations of the artefact hint

at the feasibility of automating a large scope of ITS reporting obligations for institutions using a compatible DLT solution for transactions and execution of derivatives. Once the ITS fields are enriched, regulatory local and European authorities can query the data warehouse to pull ITS data as needed.

As illustrated above, the ITS supervisory reporting regime requires modular reporting obligations at the local level and further consolidated template reporting obligations at the national level (Figure 1). The consolidated templates are subsequently prepared for the authorities at the supranational level and are subject to comprehensive data quality checks in compliance with EBA's data point model. The artefact was designed to accommodate this process by feeding ITS data into a nested data hierarchy (Table 3), enabling the compilation of macro risk assessments and systemic risk analysis in real time, as transaction data is enriched by the Composer and stored in the data warehouse (Figure 5).

Table 3. Embedded Data Hierarchy for Real-time ITS Reporting Aggregation

Local Reporting	National Reporting	Supranational Reporting
ITS modular reporting, MI reporting, Idiosyncratic Risk management, Compliance, Strategic direction, Supervision and Evaluation	Predictive local macro, Key Risk Indicators (KRI), Supervision, Systemic country risk, Local financial stability, Prescriptive feedback, Secondary template reporting	Predictive local macro, Key Risk Indicators (KRI), Policy action, Systemic regional risk, Financial stability

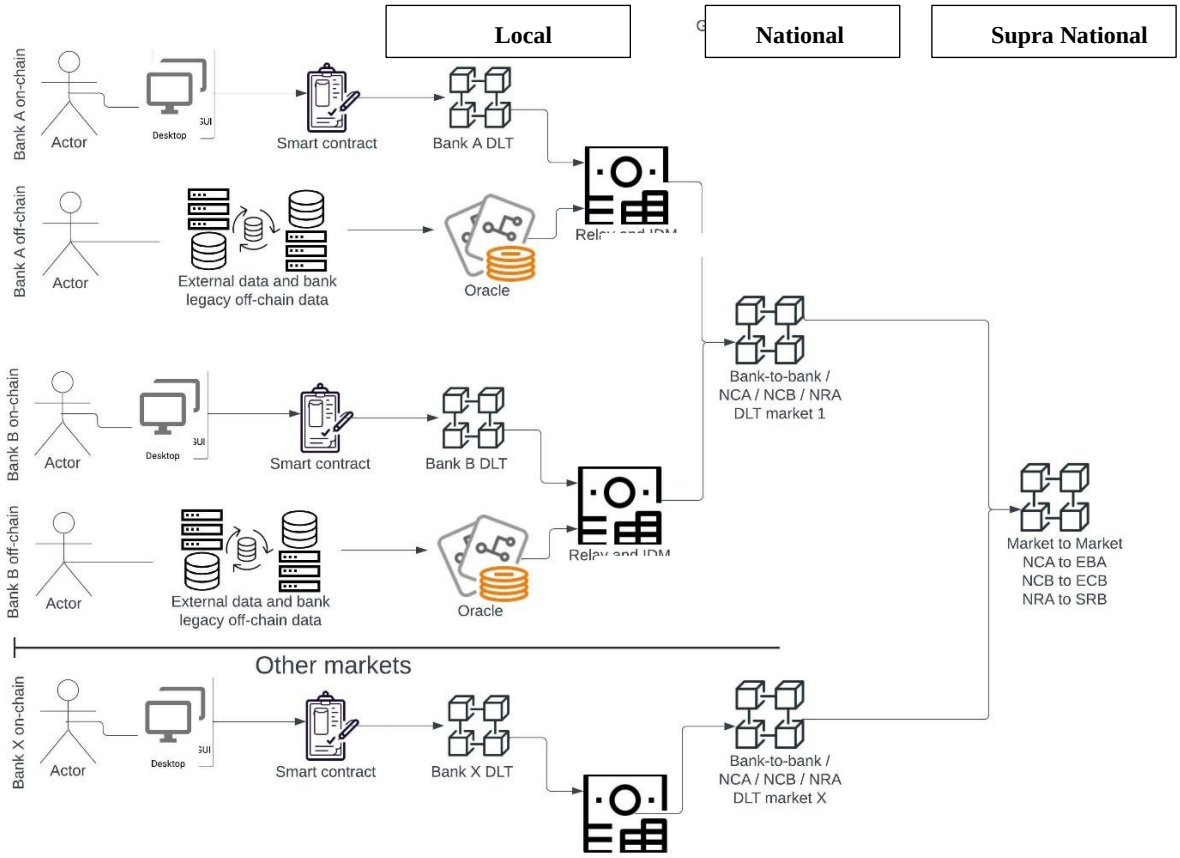

Figure 5. High-level artefact actor-model

The initial iteration of the artefact design was validated and tested through an early implementation, in which existing node-service providers were used to extract state changes from

a public blockchain network. By conducting transactions and deploying smart contracts designed to move assets between multiple owned accounts, we generated a small transactional dataset for testing. The transactional dataset was subsequently enriched with ITS dummy data to validate early assumptions about the feasibility of extracting and enriching DLT transaction data from live networks.

While the artefact design is intended to extract data from DLT nodes, the format can be implemented in a vast variety of use cases, extracting transactional data from legacy systems which may interface with the artefact through oracles. Data is then structured at the three reporting levels and extracted through complex queries, above.

5 Evaluation

While the choice of working with a broad selection of representatives from industry and regulatory backgrounds has infused the requirements elicitation process with heterogeneous perspectives on compliance, regulation, and competition, working with a 'big tent' always introduces discrepancies of opinion and priorities. As can be expected at this stage in the research process, the latest round of evaluation reveals some discrepancies in opinions of priorities, as stakeholders naturally seek to advance their mandate in the evaluation of the artefact design and future requirements. In Table 4 we feature a condensed summary of the latest round of evaluations.

Table 4. Evaluation results (the latest round of evaluation)

	Requirement's title	**Evaluation summary**
Foundation	Data sources and interoperability	The artefact conceptually demonstrates a *pull-model* reporting flow at the transactional reporting level, which can be used to aggregate reports further up in the data hierarchy. Yet, the current design fails to demonstrate how interoperability with existing legacy solutions and synthetic data sources is intended to work.
	MRER (machine readable regulation)	To the extent that regulatory documents and other formal and informal legal documents are enhanced with extensive metadata fields that tell machines and human readers of the types of impacts the document will have, and that the document pertains to, and how restrictive a given document is, the artefact may incorporate machine-readable and executable reporting requirements.
Rights	Security and Privacy	The current iteration does not implement the security standards expected by industry. Future iterations will be required to meet expectations for hardened database-architecture, GDPR confidentiality, and applicable security standards such as ISO 31000/31022 and ISO/IEC 27005.
	Delegation	The current iteration of the artefact inherits the properties of DLT to the extent that system participants are relieved of some obligations due to the "single-source-of-truth" available on the ledger.
Accountability	Data *pull* vs *push*	The artefact demonstrates the feasibility of a "pull" approach, which can hypothetically reduce the time requires for report processing from up to T+90 days towards T+0 days. It is noted that senior management regimes prescribe that management cannot relieve their responsibilities for compliance, regardless of whether a "single source of truth" system is operational. Further work is needed to investigate how this liability regime can be adopted to a DLT system.
	Relevance and Incentives	It is generally assumed that the reduction in the cost-of-compliance through automation alongside the features of DLT documented above may provide ample incentives for banks to onboard a potential solution. Yet, further work is required to understand if all elements of the ITS is suitable for automation and to which extend the artefact can be extended to integrate with legacy reporting systems.

As evident, the ongoing evaluation process reveals how IS research on DLT artefacts must be positioned to satisfy a complex web of regulatory and market-driven incentives. We believe that these findings emphasize the growing need for interdisciplinary research on the topic of DLT in industry and regulation [33]. A general point of contention which continued to surface in our stakeholder interviews is the 'radical' implications for transparency introduced by the use DLT in

the financial industries [34]. The EU supervisory data strategy objectives aims to *"modernize EU supervisory reporting and put in place a system that delivers accurate, consistent, and timely data to supervisory authorities at EU and national level, while minimizing the aggregate reporting burden for all relevant parties"* [3].

Yet, it is not clear, if the radical level of transparency introduced by DLT will push this mandate too far, by exposing sensitive data to competitors, once again underlining the need for further design-oriented IS research on the benefits and limitations of DLT in industry [35]. To achieve continued balance in the supervisory review and evaluation process in a system, where supervisors will gain an increased level of awareness of systemic and idiosyncratic risk due the transparent nature of DLT, additional safeguards will be required to ensure a balanced approach to implementing obligations for market disclosure without compromising EU mandates for free-market competition.

6 Discussion

In this article we report ongoing progress on the design of an artefact, with a group of stakeholders representing perspectives form industry and government. The artefact demonstrates the feasibility of implementing a *pull-model* for compliance data, for transactions completed with DLT. We address the research question: *To what extent could the adoption of DLT based solutions optimize ITS compliance reporting for banks and organizations in the EEA?*

The artefact design demonstrates how authorities can query and enrich DLT transaction level reporting data and ultimately stage aggregated financial exposures without disclosing underlying individual transactions. From a supervisory perspective, pulling data directly from banks' ledgers may be perceived not only radical, but counter to tradition, because supervision, as it is practiced today, is based on consolidated data, with the intent of understanding the banks' own view of their data. Traditionally, local bank managers interpret data themselves in view of their risk appetite and tolerance, allowing for ample flexibility in the calculation of fair value or risk positions. As a result, a *pull-model* may be challenging to operationalize in a secretive industry, where internal control processes are commonly practiced through the '3-lines-of-defence' model and strongly relies upon the banks' own fiduciary responsibilities [36].

6.1 Limitations

The present study contains multiple limitations. Primarily, the work towards the design of the artefact was conducted in a group of nine stakeholders, led by the author team (Table 1). The group represented industrial voices, regulatory supervisors, and central bankers. Choosing stakeholders for an evaluation process in a DSR project carries certain risks, primarily: (a) Bias (b) lack of representation, and, as a consequence, (c) misalignment with the project objectives.

The selection of stakeholders clearly introduces a pro-innovation bias, primarily as the panel does not feature representatives from the traditional practical setting in which the artefact attempts to innovate. As noted above, the radical level of transparency introduced by DLT may risk exposing sensitive data to competitors. As evident, the lack of representation from partitioners in the target field of research contributes to the evaluation assigning relatively little weight to this feature of the technology. This may, in turn, introduce misalignment with the objective of understanding the extent to which the adoption of DLT-based solutions might optimize the compliance reporting burden for banks and organizations in the EEA, as the stakeholder selection features an overrepresentation of managing and supervisory parties.

Had the stakeholder group emphasized an equal weighting of practitioners, we may have seen much more push-back on the implementation of transparent infrastructure, given the potential risk these may introduce to privacy and competitiveness.

Second, an important limitation of the presented research is that it generalizes the compliance reporting process related to prudential risk, which for many regulated institutions is unique and

will vary considerably, depending on the current level of automation. These inefficiencies and process flaws have been known for many years as part of supervisors' and regulators' ongoing review processes. The implied advantages of DLT, assume a general trend towards unified reporting standards in the EEA, which is currently not possible in the currently fragmented banking landscape.

6.2 Contributions

In lieu of the limitations presented above, our preliminary findings contribute actionable insights to the literature on DLT in the financial industries, emphasizing how DLT and blockchain technologies may significantly reduce the compliance reporting burden, while enabling faster processing time at a much lower cost. We extrapolate our contributions into four generalized propositions (P1-P4 below) on the impact of DLT in compliance reporting.

P1: DLT based compliance reporting will introduce a new level of precision in supervision: The increased level of transparency enables more effective and focused supervision and more precise and faster data sharing across the regulated entities, reducing idiosyncratic and systemic risk. Issues around loss of control, cost of maintaining platform, and the risk of intrusive supervision appear more perceived than real [39].

P2: Automation through DLT will reduce cost of compliance reporting and improve processing time significantly: The standardization of data taxonomies will lead to increased levels of automation and result in faster and more efficient compliance reporting, reducing cost significantly and eventually paving the way for embedded supervision [37].

P3: DLT based compliance reporting incentivizes more accurate reporting requirements: As authorities are tasked with creating their own view of banks' data there is a clear incentive for improving the reporting requirements and embrace the highly synergistic advances in machine readable regulation (MRER) [23].

P4: DLT will transform how compliance is undertaken: Moving towards a 'pull' model will challenge prevailing control practices such as the '3-lines-of-defence' model, that is widely used for compliance across industries. With increased levels of automation and smarter and more precise reporting requirements, there might be no need for a '5-lines-of-defence' model, with external auditors and authorities in addition to three internal lines of defence. Rather, inscription will evolve as the organizing principle, where the existing practices are inscribed in technological artefacts and control is dynamically negotiated [38].

7 Conclusions and Future Work

We investigate the implications and benefits of using DLT infrastructure for compliance reporting, as mandated by EBA's ITS regime. Through the ongoing design, implementation, and evaluation of a DSR artefact, we demonstrate the feasibility of implementing a *pull-model* for ITS data for transactions processed with DLT-based solutions. Working with a group of nine stakeholders from industry and government, we demonstrate how the artefact may reduce cost-of-compliance for banks and facilitate near real-time assessment of macro risks of systemic and structural nature at the supranational and national levels. We extrapolate the interim findings presented in this article into four general propositions on the implications of DLT, calling for more design-driven research on the application and limitations of DLT in industry.

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Do You Need a DAO?

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DO YOU NEED A DAO?
A FRAMEWORK FOR ASSESSING DAO SUITABILITY

Short Paper

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Abstract

Decentralized Autonomous Organizations (DAOs) have seen exponential growth and interest due to their potential to redefine organizational structure and governance. Despite this, there is a discrepancy between the ideals of autonomy and decentralization and the actual experiences of DAO stakeholders. The Information Systems (IS) literature has yet to fully explore whether DAOs are the optimal organizational choice. Addressing this gap, our research asks, "Is a DAO suitable for your organizational needs?" We derive a gated decision-making framework through a thematic review of the academic and grey literature on DAOs. Through five scenarios, the framework critically emphasizes the gaps between DAOs' theoretical capabilities and practical challenges. Our findings contribute to the IS discourse on blockchain technologies, with some ancillary contributions to the IS literature on organizational management and practitioner literature.

Keywords: DAO, Organizational Evaluation, Blockchain Business Models.

1 Introduction

Decentralized Autonomous Organizations (DAOs) are organizations run by rules encoded as computer programs called smart contracts. They have gained traction in recent years as a preferred organization for token-based communities operating on blockchain. Data suggests that more than 12,000 DAOs (Rikken et al. 2023) control around US$19Bn in their treasuries, owned by some 9m token holders, of which 3m are active voters (DeepDAO 2023). Despite the continuing regulatory uncertainty and the persistence of debilitating hacks and exploits, the number of active DAOs appears to grow by double-digits year after year (Bellavitis et al. 2023). This suggests practitioners continue finding compelling use cases for this novel style of organizing.

Yet, recent empirical data indicate a considerable gap between the espoused values and practical realities of DAOs (Feichtinger et al. 2023). Given the clear profit motive in issuing so-called governance tokens, critics argue that the DAO moniker is too widely used by organizations that are neither decentralized nor autonomous in practice.

While there is a growing body of multidisciplinary literature on DAOs within IS, little work has been done to ascertain whether a DAO is actually the right organizational model for governing a given product or service. This research-in-progress (RiP) paper addresses this gap in the Information Systems (IS) literature on blockchain technology. We ask the research question: "Is a DAO suitable for your organizational needs?" The research question is formulated as a binary choice, resulting in a 5-step gated decision-making framework derived from a thematic analysis of the academic and grey literature on DAO definitions and capabilities. While our contribution to the IS discourse on blockchain technologies and DAO is theoretical, the work presented in this RiP paper may also carry relevance to the IS literature on organizations (Augustin et al. 2023; Pohl et al. 2022).

2 Method

To understand how the literature developed in the short time span in which DAOs have been around as an organizational category, we conducted a scoping review of the literature (Arksey and O'Malley 2005) followed by a thematic analysis of definitions and organizational implications (Xiao and Watson 2019) through a socio-technical lens. Initiated by our research question, we first targeted search for literature across AIS eLibrary, IEEE, ACM electronic library, SCOPUS, Elsevier's Science Direct and Springer on "Decentralized Autonomous Organization." This revealed more than 19,000 results on the first five databases and more than 44,000 on Springer. Across all databases, most results were unrelated to DAOs. We then added "DAO" to the search string, which reduced the search to 1,831 and 2,546 results, respectively. Removing duplicate entries narrowed the result to a combined 3,102 results. These were sorted by relevance (weighing the full text of each document, where it was published, who it was written by, and how often and how recently it has been cited in other scholarly literature) and reviewed manually. We excluded technical papers around non-DAO autonomous systems, purely descriptive papers, and papers focusing on commercial DAO platforms or specific applications of DAOs. We then prioritized manuscripts that explored DAO definitions, typologies, and their relevance to organizational contexts, ending the search with 18 results. We then conducted a similar search on Google Scholar and cross-checked the 18 results backward and forward. Sorting by relevance, this led to a further 20 results.

As the development of concepts may include elements of practical insights (Gregor et al. 2020), we then complemented the review with 'pragmatic inference' through a grey literature search on the same search string to capture additional insights from online networks. As grey literature is not subjected to peer review, we devised a protocol for systematically evaluating the material and determining inclusion in the literature review. We lean on (Gramlich et al. 2023) in ascertaining the credibility of the grey literature. This final search added an additional three results, totaling 41 results. Aiming to provide a balanced view that encompasses emerging academic and practical dimensions, the search culminated in 30 papers with unique contributions to DAO definitions, which we included in Table 1, organized by theme.

3 Thematic Analysis of the Literature

This section features a thematic analysis of the academic and grey literature (Table 1). By synthesizing the literature, we arrive at nine themes. In recent years, the literature on DAOs has become increasingly multidisciplinary (Santana and Albareda 2022), reflecting the application of the concept across a range of sectors. Nevertheless, the primary application is associated with decentralized finance (DeFi) (Schueffel 2021). Within the IS literature, scholars consider DAOs the combination of (i) decentralized applications implemented as 'smart contracts' deployed on a public blockchain and (ii) a set of organizational bylaws directing human efforts associated with the DAO (Pohl et al. 2022; Wang et al. 2019). Implementations differ by the extent to which the organizational logic is automated *'on-chain'* by smart contracts or *'off-chain'* through legal or social agreements between stakeholders. This combination of social and technological elements has led to an array of new organizational types (Hsieh et al. 2018; Lumineau et al. 2021; Murray et al. 2021). A key point of contention in the literature is the degree to which control of the DAO can become captured by single stakeholders, challenging the ideal for 'decentralization' (Kitzler et al. 2023; Orrick 2023), which has already led some practitioners to abandon the DAO concept altogether (McConaghy 2022).

Theme	Description
Decentralization and distribution	Decentralization, key in DAO definitions (Santana and Albareda 2022), highlights the absence of a central authority, with decision-making distributed spread among members (Hsieh et al. 2018) and a key differentiator to traditional firms (Buterin 2022). This concept of a trustless, permissionless structure has persisted, recently suggesting a distinction between decentralization (Vergne 2020) and distribution (Berg et al. 2019) with likely at least 20 token-holders for long-term survivability (Rikken et al. 2023).

Autonomy and automation	Autonomy is a key attribute starting from (Vitalik Buterin 2014) through (El Faqir et al. 2020; Wang et al. 2019). The concept of automation (van Rijmenam 2019) has become a prominent feature, as automation of business processes is considered key in reducing bureaucracy(Qin et al. 2023).
Organization and operations	DAOs are generally internet-native organizations, more recently meta-organizations (Mini et al. 2021), coordinated, owned, and managed by members (Bellavitis et al. 2023; Hassan and De Filippi 2021). Organizational design theory shows an increased understanding of the characteristics of DAOs as entities that coordinate collective action and decision-making (Pohl et al. 2022).
Smart contracts and permissionless blockchains	From (Wright and De Filippi 2015) to (Rozas et al. 2021), smart contract infrastructure deployed in permissionless blockchains has been recognized broadly as the only way to run a DAO. This continues today, where public and permissionless blockchains remain the favored execution environment for DAO stakeholders. Smart contracts implement the DAO decision-making tools and the associated governance token.
Self-governance and code-based governance	The concept of 'self-governance' through code, starting from (Jentzsch 2016), is a recurrent theme from (Davidson et al. 2018) to (Wright 2021) and (Ziegler et al. 2022) emphasizing the necessity of active stakeholder participation in both 'on-chain' and 'off-chain' activities (Santana and Albareda 2022). In recent literature (Zargham and Nabben 2022), the idea that rules are formalized, automated, and enforced by software appears consistently as a qualifier for DAOs. Today, most DAOs are governed through the use of 'governance-tokens,' small scripts enabling stakeholders to vote proposals in binary decision-making processes.
Token economy and incentives	Several definitions after 2016, like those of (Voshmgir 2017), emphasize token systems and economic incentives that coordinate distributed and fluid work practices within DAOs (Schirrmacher et al. 2021). Token-based incentives can be issued in the native governance token for the DAO, equivalent to employee stock options, or in stablecoins or other crypto-assets held in the DAO treasury.
Human involvement	Early definitions, like (Vitalik Buterin 2014), emphasize reliance on individuals, whereas later definitions (Filippi and Wright 2018) move towards a vision of complete automation by smart contracts and algorithms (Faqir-Rhazoui et al. 2021). The concept of full automation has become more pronounced in later years (Qin et al. 2023), while some still remain skeptical (El Faqir et al. 2020).
The legal and formal structure	While the very early definitions did not delve into the legal implications of DAOs, this topic has become increasingly relevant, starting with (Jentzsch 2016) and (Wright and De Filippi 2015) exploring legal personality and responsibility in taxonomy development to (Wright 2021) discussing participation without legal boundary.
Scope and Potential	As the literature matured, scholarship increasingly turned towards exploring the ultimate scope of DAO governance (Atzori 2017; DuPont 2019), some seeking to stretch the limits of what the concept may accomplish (Singh and Kim 2019) at which DAOs can operate, from small companies to meta-organizations (Wiriyachaokit et al. 2022). Recent definitions (Pahuja and Taani 2022; Qin et al. 2023) view DAOs as key to a so-called 'decentralized society.'

Table 1. Key DAO themes.

4 Do You Need a DAO?

Since the initial attempts at decentralizing authority using smart contracts, DAOs have evolved into complex entities, some featuring a legal and physical presence in multiple jurisdictions. This reflects a maturation from the original concept into what are now complex, multi-dimensional organizations.

Derived from the thematic literature review, we propose a forward-looking definition that aims to capture the theoretical and practical essence of DAOs:

A DAO is a collaborative, open, blockchain-enabled platform governed by smart contracts designed to operate without centralized control. A DAO orchestrates interactions, asset management, and decision-making through coded rules to achieve common objectives, with global reach and integration with digital and virtual environments.

With this definition and the nine themes above, we propose a 5-step gated decision-making framework guided by the research question (Figure 1). The framework is designed to guide a decision-making process toward ascertaining whether or not a DAO is an appropriate choice for managing a service or product.

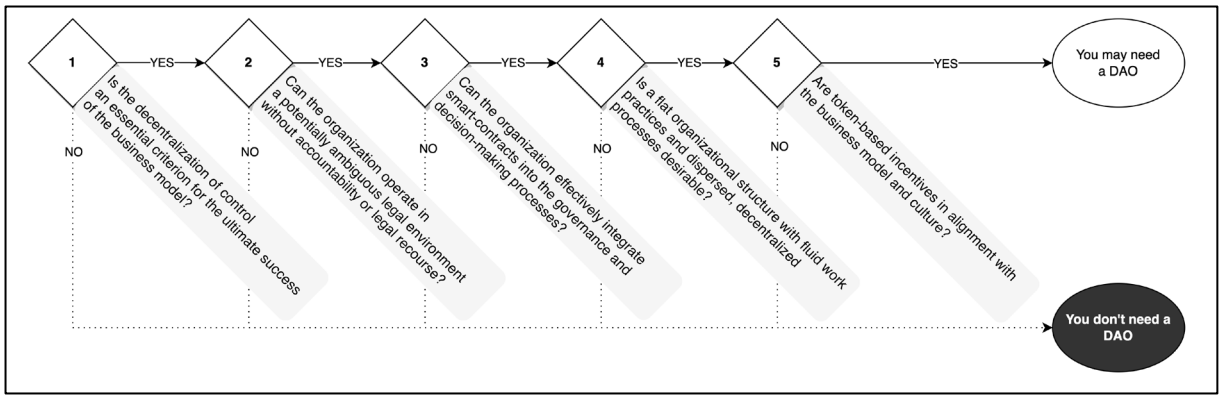

Figure 1. The 5-step Framework: Do you need a DAO.

In this section, we break down the decision-making framework,

Step 1: Is the decentralization of control an essential criterion for the ultimate success of the business model? While DAOs do not technically require a specific type of blockchain, the consensus in the literature is on permissionless public blockchains. For a DAO to inherit the decentralized and permissionless properties of the underlying blockchain, it should have an active set of at least ~20 members. This step is vital to ensure diverse opinions and prevent risks associated with centralized control, like reduced transparency and manipulation (Rikken et al. 2023). To evaluate if a DAO suits your needs, assess how well the permissionless blockchain's capabilities and your organizational goals align with the concept of decentralization. This step involves determining if the technology aligns with the organization's mission (Pedersen et al. 2019) while also fulfilling requirements for decentralization – both technologically, through the blockchain's capabilities – and organizationally regarding decision-making and governance structures (Axelsen et al. 2022). A DAO is likely not needed if these conditions cannot be met.

Step 2: Can the organization operate in a potentially ambiguous legal environment without accountability or legal recourse? To evaluate the operational feasibility of a DAO within an ambiguous legal climate, it is essential to consider the evolving legal implications and regulatory uncertainties highlighted in the literature and recent judicial practice (Jentzsch 2016; Orrick 2023; Wright and De Filippi 2015). Understanding the legal context in which DAOs operate, including the potential for members' liability and the importance of legal personality and responsibility (Wright 2021), is critical. Stakeholders must understand the legal context in which the DAO will operate, particularly the implications for liability and regulatory compliance. This ensures that the DAO is prepared to navigate the legal complexities of operating on a blockchain, especially in a rapidly evolving regulatory landscape. Without incorporation and with no one to hold accountable, there is a risk that a DAO becomes treated as an unincorporated partnership, where each member of the DAO becomes personally liable for their actions, including voting. Aspiring DAO stakeholders must understand the legal context of the services offered and organize accordingly.

Step 3: Can the organization effectively integrate smart contracts into the governance and decision-making processes? The degree of autonomy and automation determines how much a DAO can operate independently from human coordination or control by embedding business logic in smart

contracts for governance and decision-making. The advantages of doing so include the assurance of deterministic execution and increased transparency, which may reduce bias in decision-making processes. Still, the implications of embedding governance and operational procedures within immutable code require thorough consideration, given the potential for accidentally introducing adverse incentives or excessive bureaucracy. The degree of automation in a DAO can vary depending on its objective function. For DAOs with a narrow and specific objective function, full automation may be an option, eliminating the need for organizational bylaws altogether (McConaghy 2022). In contrast, DAOs with broader objectives may benefit from a hybrid model incorporating automated processes and human involvement. Viewing DAOs as complex adaptive systems, stakeholders must balance scalability and stability when adapting to dynamic environments. While smart contract design can accommodate upgradeability and failsafe systems to protect against external and internal challenges, stakeholders should only proceed if the organization can benefit from the advantages of smart-contract-based organizational infrastructure.

Step 4: Is a flat organizational structure with fluid work practices and dispersed, decentralized processes desirable? Consider if a flat organizational structure with fluid work practice suits the organizational need. DAOs represent a departure from conventional hierarchical organizations, typically having very fluid entry/exit barriers and role designations (Schirrmacher et al. 2021). A flat organizational structure promotes direct, decentralized decision-making and collaboration in which teams and stakeholders are distributed across different locations, typically working asynchronously and remotely. Adopting a DAO model requires shifting from traditional hierarchies to a distributed operational and governance approach, entailing technological and cultural changes toward autonomy and remote collaboration.

Step 5: Are token-based incentives in alignment with the business model and culture? Various definitions post-2016, such as (Voshmgir 2017), emphasize the role of token systems and economic incentives in coordinating distributed work practices within DAOs. This aspect is critical for understanding how token-based incentives can align with or diverge from an organization's business model and culture. The literature presents a spectrum of perspectives on the role of human participants within DAOs, spanning reliance on individuals for certain tasks (Vitalik Buterin 2014) to later definitions, proposing complete automation (El Faqir et al. 2020). Stakeholders considering DAO governance must consider how token-based incentives might impact engagement and participation (Schirrmacher et al. 2021). Incentives drive behavior, which requires clear and quantifiable objectives. If these are not present, achieving anything may be difficult and frustrating compared to traditional organizations. Thus, careful consideration must be given to (i) whether incentive-driven work practices can be implemented without introducing apathy, (ii) the degree to which pseudonymity is an engagement problem, (iii) which voting-based decisions should be made immediately vs. longer term, and whether they are permanent or temporary; and (iv) how contributions should be assessed and rewarded; DAOs focusing on building a relationship-driven culture may reward mainly activities, others with a more transactional culture may primarily reward results.

5 Discussion

Through a thematic analysis of the academic and grey literature on DAOs, we propose a forward-looking definition of DAOs and derive a 5-step gated framework, guiding the decision-making on whether a DAO is the right choice as an organization. Our research contributes to the theoretical understanding of how DAOs integrate with organizational theory. It also serves as a practical guide, reflecting DAOs' potential as emergent organizational forms within the convergence of social and technological dynamics.

The concept of DAOs took root with the advent of Ethereum and improved smart contracts from 2014 onwards. That period marked the beginning of DAOs' practical applications (Jentzsch 2016), showcasing their potential and identifying some of their challenges (Wang et al. 2019). Since then, DAOs have evolved and now cover a range of applications across industries, but the challenges remain.

Our preliminary analysis indicates that DAOs may excel in scenarios where distributed governance and collective decision-making can harness diverse perspectives, democratizing the organizational process and potentially leading to more equitable and innovative outcomes. For industries or projects centered around collaborative open-source ventures, the transparency, audibility, and shared ownership facilitated by DAOs might enhance trust and alignment among stakeholders while overcoming their shortcomings in complexity. This may be particularly relevant where global participation is too difficult or costly through traditional organizational forms.

Our preliminary analysis also suggests multiple cases in which stakeholders in open-source and non-hierarchical organizations will not benefit from establishing a DAO: (1) Primarily, situations in which stakeholders have a centralized control preference or require centralized leadership and decision-making. This may be the case when managing stakeholders face regulatory and legal constraints, as the pseudonymous and permissionless nature of DAOs can conflict with industries or regions that demand clear accountability and specific legal structures. (2) Business models needing nuanced, expert-driven decision-making may find DAOs' reliance on smart contracts and member voting inadequate. If rapid adaptation to external shocks is needed, reliance on decentralized consensus and smart contracts may be too cumbersome. On the other hand, for businesses that do not require agility and rapid decision-making, the risk of member apathy or low engagement can become an issue when faulty implementation of incentives causes excessive bureaucracy or stakeholder apathy. (3) For business models with very narrow objective functions, automatable objectives may render the complexity of DAOs unnecessary. A DAO operating in a simple operational context could introduce security vulnerabilities or attract unneeded regulatory attention to an otherwise functional product. Thus, implementing a DAO for narrow objectives might lead to inefficiency and wasted resources. Even worse, in cases where operations can be automated, implementing a DAO could ironically lead to centralization, as the control might effectively rest with a small group of individuals who design and maintain the automation processes.

With the concept's gradual maturity, DAOs now represent diverse organizational solutions, leaving stakeholders to decide on the trade-offs between opposing organizational objectives. While DAOs may not fit traditional organizational models or policy objectives, their potential to redefine collaboration, ownership, and decision-making in the digital age offers a compelling solution within the identified limitations. This perhaps indicates a pathway toward more dynamic, inclusive, and resilient organizational forms.

Looking forward, DAOs may be poised to evolve towards more sophisticated governance models, focusing on ethical considerations and potential synergies with emerging technologies such as AI and IoT. Considering the challenges identified, the IS community must remain vigilant of technological advancements and regulatory shifts, underscoring our research's role in equipping practitioners with the knowledge to navigate these developments.

6 Conclusion

In this research-in-progress paper, we explored the DAO governance domain through a thematic analysis and literature review. We derive a forward-looking definition and a 5-step decision-making framework. Motivated by our research question, we then explore the challenges DAO governance may pose in a rapidly evolving digital and regulatory landscape.

Our findings offer actionable insights for navigating the increasingly complex technical landscape emerging in academic and practitioner literature. These insights are valuable for IS scholars and practitioners considering venturing into the field of DAOs because they can aid in informed decision-making regarding the feasibility and challenges of DAO governance. To this end, we contribute to the growing discourse on DAO within the IS literature on the application of blockchain technologies and organizations.

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Scaling Culture in Blockchain Gaming:
Generative AI and Pseudonymous Engagement

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Abstract:

Managing rapidly growing decentralized gaming communities brings unique challenges at the nexus of cultural economics and technology. This paper introduces a streamlined analytical framework that utilizes Large Language Models (LLMs), in this instance open-access generative pre-trained transformer (GPT) models, offering an efficient solution with deeper insights into community dynamics. The framework aids moderators in identifying pseudonymous actor intent, moderating toxic behavior, rewarding desired actions to avoid unintended consequences of blockchain-based gaming, and gauging community sentiment as communities venture into metaverse platforms and plan for hypergrowth. This framework strengthens community controls, eases onboarding, and promotes a common moral mission across communities while reducing agency costs by 95 pct. Highlighting the transformative role of generative AI, the paper emphasizes its potential to redefine the cost of cultural production. It showcases the utility of GPTs in digital community management, expanding their implications in cultural economics and transmedia storytelling.

Keywords

Blockchain, Generative AI, Scaling Cultural Production, Agency Cost, Gaming.

Introduction

In the intersection of cultural economics and technological innovation, the management and understanding of rapidly scaling cultural groups presents novel challenges. These challenges include (i) maintaining cultural identity amid hypergrowth, (ii) managing pseudonymous interactions that can obscure intent and behavior, (iii) ensuring equitable value distribution within decentralized structures, (iv) adapting to the evolving norms and ethics of a growing community, and (v) mitigating risks associated with the integration of blockchain technologies and their economic implications.

The economic problem we focus on in this paper is the scaling of the production of culture during hypergrowth (Izosimov, 2008) using the example of blockchain based gaming. This is hard, especially when the core production is culture, and the business expands rapidly; the annual growth rate hits high double-digits, and human capital needs grow dramatically (Valencia, 2019).

The cost function of human community curation encapsulates the monetary expenses tied to salaries and tools, the time spent on onboarding and content review, and the emotional toll from managing negativity and making continuous decisions, coupled with indirect costs related to reputation and potential legal risks. Organizations need the appropriate personnel and structures to drive their rapid growth. These are necessary to stay healthy. This is expensive, and balancing these costs often necessitates a blend of human and automated interventions. This is also the case for virtual blockchain-based gaming startups and generally any startup, including games organized in Decentralized Autonomous Organizations (DAOs), such as Decentraland.

This paper is about the innovation of using AI to perform that function better. We explore this problem with blockchain-based gaming communities adopting a device-agnostic metaverse model and planning for hypergrowth across different platforms, blockchains, and brands. We introduce a novel method of cultural analytics leveraging a class of Large Language Models (LLM), specifically a suite of open-access Generative Pre-Trained Transformer (GPT) models to address the following research question: “Are LLMs an option for identifying, nurturing, and sustaining culture in gaming communities going through hypergrowth?”

We considered four hypotheses: (i) pseudonymous actor intent can be predicted from online activity, (ii) large language models can make mass content moderation effective and efficient, (iii) a common moral mission can be implemented across communities, and (iv) there is a huge automation potential to reduce moderation costs in off-chain governance of decentralized communities.

Our findings suggest that the combination of AI and Blockchain tech stacks hold significant potential to solve the problem of scaling culture production in

blockchain-based business models while reducing agency costs. By extrapolating our findings, we offer the following general propositions on the impact of using open-access generative AI to support cultural production in growth:

(i) Cost-effective open-access Large Language Models (LLMs), such as OpenAI's GPT, present an opportunity to automate innovation in managing societal and cultural groups. (ii) LLMs highlight a spectrum of decentralization in the blockchain and internet-based creator economy, with tools like GPT offering both fully and semi-decentralized strategies for curating experiences. (iii) Their integration with blockchain gaming can streamline moderation and cultural preservation, adaptable across games. However, (iv) generative AI's capacity to craft narratives could challenge human uniqueness and face potential backlash. Moreover, (v) businesses' reliance on centralized APIs, especially in a decentralized context, introduces governance and operational risks and potential privacy concerns, urging caution in long-term commitments.

We contribute to the transmedia storytelling discourse with (i) the application of a contribution-based business model focused on collaboration, teamwork, and contribution around a common moral mission when transforming from web2 to a decentralized, blockchain-based internet, the so-called web3, (ii) the governance of blockchain-based business models by introducing generative AI-based supported community management policies, (iii) meta-sustainability by internalizing sustainability values at an individual level while developing a collective mindset that understands the importance of doing the right things the right.

Method

Background to case study

Blockchain-based gaming promises to counterbalance power in production, enabling players to earn and retain value, and offer enhanced openness and integration between games and their underlying blockchains (Egliston & Carter, 2023), and major brands increasingly want to participate in the emerging disruptive business models (X. Nguyen, 2023). Such crypto gaming use tokenization and smart contracts and are reshaping the gaming economy by allowing players to monetize assets and gain enhanced control over their experiences.

Cultural science suggests that culture, through its evolutionary and complex nature, facilitates group formation and stimulates knowledge and innovation and promotes social cohesion, where shared practices and symbols within groups reinforce identity (Hartley & Potts, 2014). Platforms like Discord are essential in fostering this digital interconnectedness in decentralized models by transforming

players from consumers in traditional pay-to-play (P2P) games into producers and owners of blockchain-issued non-fungible tokens (NFTs). As players profit through play-to-earn (P2E) mechanisms, akin to stock options in traditional firms, they also have the potential for real-world trade. However, the dominance of such profit-driven incentives may pose risks (Delic & Delfabbro, 2022), including potential exploitation and mental health concerns, such as technostress from addiction, urging developers to monitor and address potential harm.

With the emergence of web3, with no centralized authority controlling or regulating the network, Decentralized Autonomous Organizations (DAOs) (Santana & Albareda, 2022) are proliferating as an emerging organizational form to support creator economies, also in gaming (Egliston & Carter, 2023; Glaveski, 2022). DAOs operate as decentralized, fluid organizations through token-based working practices with pseudonymous actors, making it difficult to define relevant externalities (Axelsen et al., 2022). Yet, despite the DAO concept and typology being nascent and still developing, it has been suggested that DAOs could further confront the societal problems plaguing the metaverse, the current focus of many web3 gaming studios, by providing incentives to drive behavior in the required direction, with decentralized control of data, a greater level of user engagement, ownership and involvement (American Enterprise Institute, 2022).

Decentralized community projects, including DAOs, could be considered projects to create digestible stories. “The narrative must fit the community as well as the project” (Shorin et al., 2021), and the core community members must believe that community moderators manage the story, the mission, and divergent stakeholder interests. Measures must be implemented to scale, as the case of CityDAO suggests (*CityDAO*, 2023), where a tokenized collective experienced hypergrowth, after some crypto notabilities purchased NFT-citizenships in 2021, resulting in temporary sellout, an unsurmountable workload, and the DAO deciding to halt most external operations, while building infrastructure to allow better scaling (Taken, 2022).

Participants

In 2017, the subject of this case study, gaming studio startup Reality+, forked the Ethereum blockchain to create unique approach to brand specific NFT collections for card gaming in a so-called free-to-play (F2P) model. As they now transition to a metaverse model with customers scaling globally, their NFTs grant players avatars, seasonal awards, and other perks, and Reality+ is increasingly becoming a metaverse service for mega-brands that aim to amplify their narratives through transmedia storytelling (Perryman, 2008).

With around 250,000 current users and a projected 5 million by 2024, Reality+ seeks a strategic approach to manage its growing community and ensure

sustainable scaling into what observers estimate will become a US$ 8-13 Trillion business by 2030 (Burke, 2022). Among its customers are BBC Studios (Doctor Who and recently 26 other BBC brands), ITV (Thunderbirds, Love Island).

To advance the creator economy surrounding their web3 gaming models, Reality+ considered establishing a DAO to harness its community's affinity as it continued its high-growth journey, while distributing fair profits to community contributors. Yet, while the digital work practices of the communities in the gaming platform operate very decentralized and are like those in DAOs, the DAO concept and decentralized governance conflicts with the need for the customer mega-brands to remain in control of their brand IP. Hence, Reality+ is experimenting how to combine a decentralized gaming platform with traditional business IP-controls.

The most popular game in Reality+' universe is Doctor Who Worlds Apart (DWWA), based on the world's longest-running sci-fi series (Bell, 2020) that has held significant cultural influence in the UK and beyond for the past 60 years. With numerous global fan communities, Reality+ emphasizes the Doctor Who gaming card and web3 experience. This gaming experience also serves as the blueprint for the entire Reality+ game ecosystem, attracting other brands seeking web3 and metaverse experiences.

At the time of research, a dedicated gamer spends US$1000 annual recurring revenues (ARR) in line with mature video gaming, some 27x higher than casual gamers in traditional F2P trading card gaming. The F2P model is subject to high churn in line with the industry, but also high net growth.

The Community and the Metaverse

Out of approximately 250,000 wallets on the Reality+ NFT platform, about 75,000 are tied to DWWA. Notably, a subset of around 3,000 form the gaming community, with 1,100 actively participating in discussions. A team of 30 part-time moderators oversees this community. However, in addition to the risk of a "CityDAO" experience, there is a concern that unchecked growth may dilute the community's appeal, especially as associated brands like BBC expand their global reach via platforms like Disney+.

Reality+ aims for device-agnostic operations, but currently revolve around Discord for community management, with games tied to the Ethereum blockchain. As they migrate into metaverse platforms they aim to embed a worldview promoting ethical avatar behavior (Park & Kim, 2022). Yet, advanced metaverse platforms like Sandbox and Decentraland blur online and offline personas through decentralized structures, blockchain, and DAO governance (Dwivedi et al., 2022; Egliston & Carter, 2023), and despite advancements, a fully

immersive metaverse remains elusive, but the direction is clear: In a metaverse context, composability and interoperability, using DeFi protocols (Werner et al., 2021), are essential.

Contrary to the general crypto industry, Reality+ is also cautious of potential regulatory issues around DeFi..

In this context, the DWWA card game epitomizes Nguyen's "art of agency" theory (C. T. Nguyen, 2019). It offers players dynamic narratives, profound moral choices, and collaborative experiences, all while maintaining game integrity and compliance with external stakeholder expectations. Drawing from DWWA, Reality+ has established a compelling gaming approach, where web3 assets and real-world connections are fortified and now enrich partnerships with sports leaders like FIFA and Velon by offering players a harmonized blend of strategy and story, operating within distinct communities, yet linked to an overall platform with a common moral mission.

Community challenges

Community challenges and requirements were identified through semi-structured interviews:

1. Scaling a factor 20X over the next year while avoiding the chaos CityDAO experienced and keeping curation costs low.
2. Understanding who customers are vs. stakeholders/creators and how to effectively spot these. Although segmentation of online gaming motivation using analytical methods is not new (Kahila et al., 2023; Tseng, 2011), the moderators have so far been unable to model this, failing to identify the relevant annotation variables; but having a clear view of what personas they are looking for – crypto investors and dedicated gamers. They observe valuable community and game contributions but cannot identify in advance who, when, and where the contribution is delivered and with what intent before it has been delivered. Understanding intent a priori would help moderators greatly in providing the relevant onboarding procedure.
3. Increased risk from toxicity in gaming environments entering a metaverse scaling journey encapsulating other franchises requires smarter ways to moderate community chat effectively.
4. Although most community members mirror the Doctor Who characters' behavior and agree that this is a moral compass for them, some members are more extreme, representing cult fandom, which may cause division around innovation.
5. Understanding culture production and how to create internal controls for managing stakeholder expectations.

6. Institutionalizing a balanced incentive model to address the unintended consequences of the new business model.

Specific to the scaling plans and need for more resilient infrastructure, the moderators and founders delineated the set of requirements as follows:

1. Design a model development framework to create a cost-effective rapid deployment classification system for cultural aspects of the community, using a cultural science approach to identify improvements needed for scaling/hypergrowth.
2. Develop a suite of analytical models with good to very good F1-scores to understand, automate, and flag to moderators for their further curation (a) intent of pseudonymous actors and classify stakeholders for proper onboarding, (b) unwanted behavior to penalize/moderate, (c) desired behavior to reward with NFTs or other perks for meaningful contributions as part of a "proof of contribution" concept.
3. Outline the community's sentiment and key drivers of "meaningfulness" and assess the general cultural sentiment to enable understanding and planning for a resilient growth journey.

Procedure and Apparatus

For interviews and workshops, we chose an explorative, qualitative approach to the classification of cultural practices leveraging the cultural science method. This process led us to workshop critical elements of the cultural practices within the community and how to assess their maturity and identify opportunities for improvement. The unit of analysis was the practices undertaken by the community, the story of the Doctor Who franchise, its characters, how the show had affected the community culture, and the developing plans to migrate the game to a metaverse platform while preparing for hypergrowth.

Moderators supplied us with chat data from the community's Discord forum to investigate the potential of using AI to automate and improve community management. Since its inception 18 months prior, the data scrape include over 65,000 chats. A data consent form was shared to comply with GDPR requirements for research projects. In a subsequent replication experiment to another Reality+ game community, Thunderbirds, another long running British science fiction series, a data scrape covering 102,000 chats was provided.

For the analytics part, large language models (LLM) models easily align with user needs and human feedback (Ouyang et al., 2022) to classify a range of issues, including the assessment of intent by leveraging language processing to analyze large volumes of text, for example from online communities, using embeddings

for search, clustering, recommendations, anomaly detection, diversity measurement or classification (*OpenAI API*, 2023).

Where previously, it was necessary to fine-tune LLMs on datasets of thousands of examples for good performance, OpenAI's recent launch of GPT3 and -4 allow scaling up a language model with only a few examples (few-shot learning) to achieve similar performance (Brown et al., 2020).

Creating an LLM is not a small task but requires a specialized programming team and expensive hardware with a powerful GPU to run the model and handle a big dataset. There are several ways to model the problems analytically, which could likely all yield good results but would come with different risk/return trade-offs, which were discussed with the moderators and all boil down to a question of data availability, performance, and cost:

1. Train our own natural language classifier using, e.g., word embeddings and Long Short-Term Term Memory (LSTM) architecture.
2. Use a zero-shot LLM (no training required) such as OpenAI's text-davinci model.
3. Fine-tune an existing LLM (few-shot learning) such as OpenAI's ada model.

The recent rise in model complexity and limited open-source access have spurred model acceleration methods, notably knowledge distillation. This technique has a larger model teach a smaller one, allowing cost-efficient models to harness the advantages of bigger models for tasks needing less complexity. Such practices, like in-context and few-shot learning, are gaining traction among researchers aiming for content analysis. Given the limited team size and resources, our goal was to find less resource-intensive alternatives to traditional analytical processes.

Open-access GPT models could automate community moderation aspects, making it cost-effective for new communities. Leveraging OpenAI's GPT3 API was ideal due to its model variety and potential for low-cost prototyping, deferring the bulk cost until production. The GPT-3 model suite is apt for zero-shot learning. However, the specific weights of these proprietary models remain undisclosed, and our approach therefore technically is not true distillation, but applies distillation principles with zero-shot learning, creating an initial dataset that is then curated by humans. Through iterative fine-tuning, more examples are generated and validated by moderators, mirroring traditional taxonomy development but faster and cheaper.

Apparatus

Rapid development framework

We designed the following procedural steps to rapidly create a suite of models based on the API:

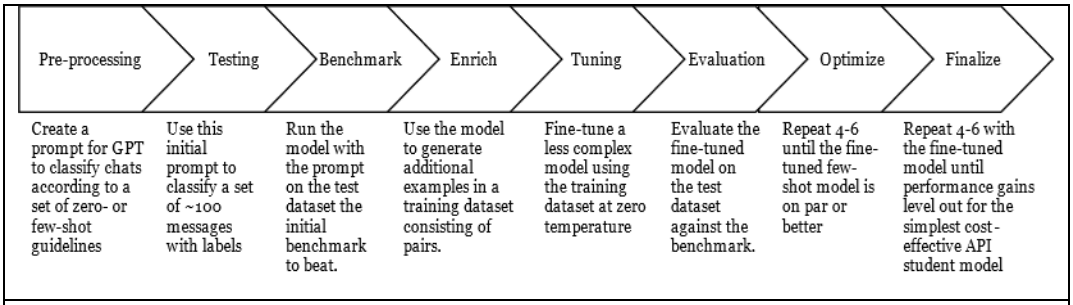

Figure 1. Rapid development process

If a model is not performing meaningfully after step 3, we would first add additional manually annotated chat examples to the training dataset and re-train the model on a larger sample of training data. If the model is still not performing, it may be that the problem is not a classification problem. In this case, first, we let more than one person classify and validate the dataset to check the consistency of human annotation. If the answers are subjective, it can be challenging to evaluate the success of each response using classification and labeling, but it may require prompt engineering. Tasks such as open-question answering may involve manual grading and curation. This can be a concern since human graders bring their biases to the task. To reduce this, multiple graders and consensus metrics were needed for the curation process, implemented through detailed annotation guidelines, validated by the moderators.

Figure 2 provides an overview of the framework architecture, linking off-chain cultural practices through models, curation, and NFTs.

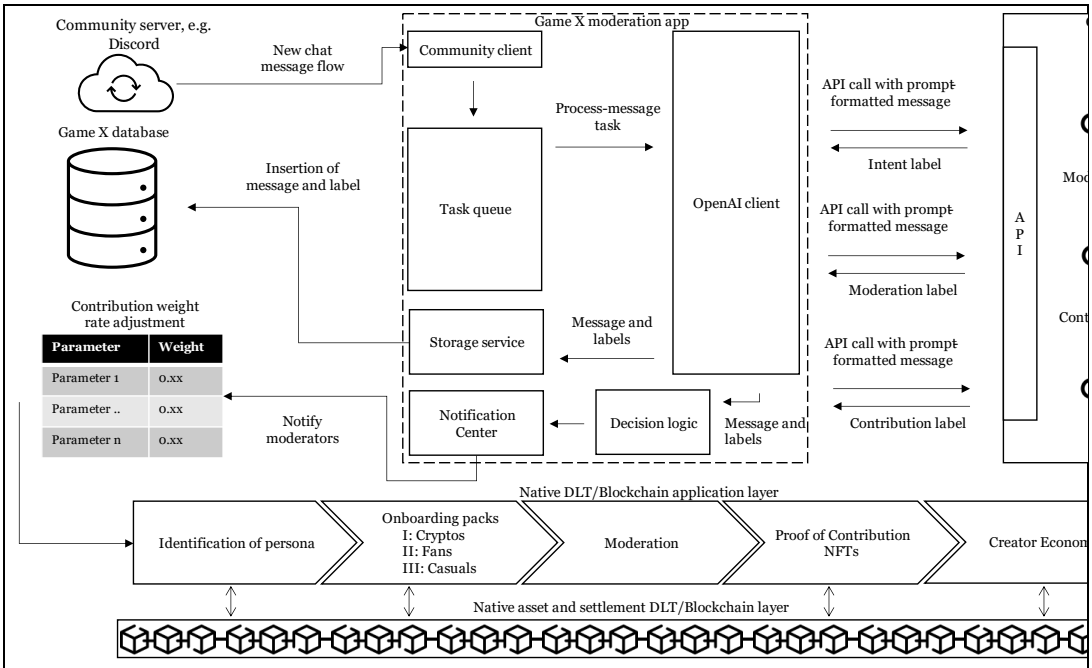

Figure 2. The technical and operational architecture for the framework

The community moderation teams had previously without success utilized analytical and cartographic tools for community management within Discord, yet the identification of key personas and contributions remained challenging. Our primary objective was to devise a predictive model to classify message intent in the Doctor Who community based on user activity and then convert this to user intent through a rules-based approach. Collaborative workshops with the founder and moderator team resulted in the identification of three primary personas in the Reality+ gaming community:

- Cryptos: (a) NFT speculators who engage in community dialogue and anticipate a return on investment, and (b) Flippers, short-term investors with minimal community contributions but potential future speculators.
- Fans: Collectors emotionally attached to their cards, adding significant value to the community. This aligns typology-wise to "strategizers" in a metagaming context (Kahila et al., 2023).
- Casuals: Players focused on gameplay rather than NFTs, with minimal community contributions.

Moderators noted consistent persona behavior across games and geographies, suggesting shared cultural tendencies, implying an overarching Reality+ ethos

transcending Doctor Who's core fandom. To classify intent, we refined an OpenAI ada model using 463 manually labeled and curated chat messages and validated its performance against a test set of 116 labeled chats. We later tested this on another game, Thunderbirds, as further outlined below.

Moderation model

User perceptions of community moderation can influence norm enforcement in social media, making it crucial for automated moderation to be viewed as fair and just by the community (Gonçalves et al., 2021; Myers West, 2018). OpenAI's GPT series has a built-in moderation model for toxic content, offering added value. Yet, testing revealed issues like flagging gaming or blockchain terms as violent and overlooking spam leading us to reject this option. We trained the GPT model using the public Kaggle "Toxic Comment Classification Challenge" dataset to address this. Initially, attempting a model using only the Kaggle data led to overfitting. Integrating past moderation data from images of deleted chats, presented another challenge, which was overcome with the use of open-source extracted using Optical Character Recognition software. We initially trained the model using eight predefined labels from both datasets. Still, the model remained overly sensitive to certain keywords.

A 3rd iteration with reduced labels prioritized context over specific terms, showing improvement. We then tried a reduced set of labels, as the practical use test was flagged for further human curation anyway. The rationale was to reduce the model's dependency on the labels and look further into the context of the message as such, not the label. This model performed better than the first iteration but still did not meaningfully capture the community language. In the final model, we then replaced the not_toxic messages in the dataset with actual community chat examples from the Discord database, which significantly reduced the false-positive rate and adjusted the model's ability to comprehend how these keywords could be used in a non-toxic manner. The final dataset for testing consisted of 383 out-of-sample chats.

Contribution model

Historical reward instances, termed "fatfingers" in the community—referring to airdrops from the co-founders' Discord handle, the "FatViking", were initially gathered to develop the model. These rewards were highly valued by the community as these were often rare NFTs that could accrue significant financial or status value. However, most examples were private appreciations from FatViking rather than public chat messages suitable for model training, but the data provided a foundation for zero-shot modeling, highlighting valuable contributions such as:

- Reporting bots/spam links/fake accounts,

- Educating newcomers on the trading card game, blockchain, and NFTs,
- Sharing crypto and airdrop updates,
- Expertise in Doctor Who characters and lore,
- Welcoming and providing constructive advice,
- Updating the community on Doctor Who news,
- Promoting the Doctor Who trading card game,
- Offering support to new members,
- Steering conversations positively.

This led to a 2-phase development approach:

1. Test OpenAI's chatGPT3 and -4 to tag messages in the dataset exhibiting the behavior outlined.
2. Design a proactive contribution policy grounded in FatViking's past actions and enriched by behaviors vital for growth and institutionalizing the "proof of contribution" idea. The model should assign varying weights to diverse attributes, enabling moderators to guide and adjust rewarded contributions. Additionally, it should allow contributions to build over time, potentially transitioning to decentralized community reputation systems like (*SourceCred*, 2023) or (*Coordinape*, 2023) or even integrating into future algorithmic governance models through smart contracts, once the ecosystem has mature and curation becomes consistent across communities to allow for full automation without human curation.

The new contribution policy was designed based on a series of consultations. To ensure holistic coverage of the policy objective of meaningful contribution, a total of 21 attributes were suggested to be included in the curation of appraisal going forward, which should feed subsequent retraining of the model to adapt to the policy as the business model evolved. From this qualitative search process, 8 of the 21 attributes identified were deemed sufficiently objective to parametrize and model, using the development framework.

Sentiment model

The sentiment classifier estimates what the sentiment of a message is, i.e., is it positive or negative or neutral? Messages were annotated manually and validated with the moderator team and founder, with positive examples of messages that fit the label, such as "Hey that was a great game!" expressing excitement and happiness about the game, and negative examples, such as "Man that sucked" expressing disappointment or sadness about something being examples of messages that fit a negative label. Neutral sentiment would be used to annotate messages with no emotional or opinionated content, such as "Yeah that's just the way it is." These serve as a reference for annotators to draw a distinction.

Results

Qualitative context

The community is still young and is characterized by the founders' and original character value sets, which the community moderators described as inclusive, welcoming, and relationship-driven. There were 11 working groups in the community based on allocated roles, of which there are more than 30. From the semi-structured interviews, this culture could be described by the following traits from cultural science:

The people consist of the identified persona groups cryptos, game fans, and casuals, alongside the moderators and the Reality+ developer and founder team. The community language was generally very mature and unique to the specific game and crypto, covering the breadth of the community. The collaborative practices were informally implemented, not consistently managed, and only sometimes documented to evidence consistent coverage. The moderator team and founder appeared to have a very good understanding of the risk to the franchise if onboarding, contribution management, learning, and moderation were not further developed and institutionalized as the franchise prepared for a hypergrowth phase.

The infrastructure technologies consisted of devices (currently PCs only), blockchain, and metaverse technologies relevant to each metaverse chosen by Reality+ and the associated metaverse AI and XR functionality present (Park & Kim, 2022). The institutional technologies identified to underpin the culture were (1) NFTs minted, sold, or awarded (airdropped) by Reality+ for meaningful contributions; (2) Avatars, many of which could only be earned through community contribution; (3) Emotes (expression for doing a good job – emotional expression and visual emoji); (4) Pandaks – an in-game virtual currency used as in-game currency utility token as a free-to-play currency pegged to US$, only accessible through contribution earning in-game; (5) Founders token (FT), which could be bought, but also earned, with limited circulation.

We tested if we could use the rapid model framework to guide us in understanding the main cultural drivers creating meaningfulness in this community. However, the chats were too ambigous to deliver acceptable results, revealing an unimpressive Krippendorff alpha (Krippendorff, 2018) of 0.254 among a panel of 4 humans per step 10 in the development framework.

Several symbolic cultural elements were identified in the community interview process: (a) Due to Doctor Who's rich history, storytelling emerged as a pivotal aspect of community significance. (b) Knowledge and education varied across individuals, with potential enhancements via interactive tutorials and persona-specific onboarding. (c) While there was an active push for innovation, it was sometimes limited by brand intellectual property guidelines. Yet, the

community's culture remained unaffected, possibly due to a reward system emphasizing contribution efforts over results. (d) Community behaviors and contributions were primarily influenced by the intrinsic characteristics of the Doctor Who character, and a contribution and reward system centered around NFTs and perks. This system rewarded community growth activities and promoted kindness, inclusivity, and fun. Minimal negative behavior was noted, possibly attributed to robust moderation and the community's manageable size.

Using an archetype model (Cameron & Quinn, 2011), the “Fan” personas had a strong sense of belonging, loyalty, and emotional attachment, reminiscent of a Clan culture. They formed communities where shared passion, narratives, and experiences were central, similar to “strategizers” in the typology presented by (Kahila et al., 2023).

The other key persona group, “Crypto” was more aligned with a Market culture. Their main motivation was often profit, and they operated in a competitive environment where information, timing, and strategic positioning were crucial for success, aligning with the perspectives of (Egliston & Carter, 2023) about the characteristics of cryptogaming. This persona group differs from the typology presented by (Kahila et al., 2023), yet appears to be relevant in blockchain-based games, where DeFi and token economics are an integrated part of the game experience. Given the NFT market's innovative and nascent nature, there might also be Adhocracy elements for both persona types, requiring adaptability and willingness to take risks. The third persona group “Casuals” align with Kahila et al.’s typology “Casual metagamers”.

The model development framework

The complexity of prompt engineering was demonstrated in the use case, where several iterations were needed for the more difficult classification challenges in moderation and contribution.

Intent model

	Precision	Recall	F1-score	N messages
Crypto	0.92	0.80	0.86	41
Fan	0.93	1.00	0.96	40
Casual	0.86	0.91	0.89	35
Accuracy			0.91	116
Macro avg across	0.90	0.91	0.90	116

Weighted avg	0.91	0.91	0.90	116

Table 1. Intent model results

The model performance results were production-ready after three iterations of fine-tuning with an estimated model development time of 18 hours over two weeks to allow for processing time for the manual labeling of the 463 chat messages. After fine-tuning the intent model, we ran it on the full database initially supplied by the moderator team. Excluding all empty messages and those from well-known bot accounts, for a total of 59,910 messages across 1,121 active users in 10 channels, the messages were tokenized per OpenAI's API guidance. The full loop took 6 hours to complete, and results showed that approx. 52% of the entire Discord conversation was casual chatter, 25% was related to the gaming universe, and approx. 18% was related to crypto. Categorizing users with three or more messages classified as "crypto" as Crypto Enthusiast personas, users with three or more messages classified as "fan" as Fan personas, and users who are neither Crypto Enthusiasts nor fans as Casual personas suggested 343 unique (pseudonymous) IDs, or app 31% of the active community were Crypto Enthusiasts, 243 or 22% Fans and 716 or 64% Casuals.

Moderation model

	Precision	Recall	F1-score	N messages
Toxic	0.95	0.99	0.97	106
Spam	1.00	0.89	0.94	9
Not_toxic_not_spam	0.99	0.98	0.99	268
Accuracy			0.98	383
Macro avg	0.98	0.95	0.97	383
Weighted avg	0.98	0.98	0.98	383

Table 2. Moderation model results

Given the use case of this moderation tool, we wanted to minimize Type II (false negative) errors, as these are by far the most damaging to culture. Suppose the model wrongly classifies a non-toxic message as toxic. In that case, it is a minor annoyance to the moderator with the additional curation effort; in this case, less than 2 out of 100 flags, while wrongly classifying a toxic message as non-toxic, could be very detrimental to users and drive them away from the

community. As the model is implemented, the model should be retrained regularly to further reduce the false negative flags.

Contribution model

	precision	recall	f1-score	support
na	0.89	0.93	0.91	156
onboarding	0.75	0.9	0.82	10
knowledge_tcg	0.57	0.5	0.53	16
knowledge_fan	0.67	0.6	0.63	10
knowledge_crypto	0.5	0.25	0.33	4
content	0.71	0.71	0.71	7
moderation	0	0	0	1
suggestion	0.5	0.29	0.36	7
accuracy			0.83	211
macro avg	0.57	0.52	0.54	211
weighted avg	0.82	0.83	0.82	211

Table 3. Moderation model results

The initial contribution model proved challenging to develop. We first used a zero-shot prompt with the text-DaVinci-003 model to classify messages, but manual checks revealed inadequate quality, potentially due to a vague prompt and random message sampling. Building on a pre-established contribution taxonomy, our second strategy yielded only some satisfactory results. Eventually, recognizing that chat contributions often occur in dialogues, we incorporated the context of the two preceding messages into the model, considerably improving accuracy. While the results table demonstrates the model's ability to detect community contributions, there is room for improvement. Amplifying the training data could enhance outcomes, but the current model was deemed adequate for production, aiding in moderating and annotating contributions through future curation.

Sentiment model

The initial model for benchmarking	Precision	Recall	F1-score	N messages

delivered acceptable performance out of the box, roughly equal to the human baseline for sentiment agreement levels (Lexalytics, 2023; Ribeiro et al., 2016).				
Positive	0.75	0.75	0.97 75	32
Neutral	0.69	0.71	0.70	28
Negative	1.00	0.93	0.97	15
Accuracy			0.77	75
Macro avg	0.81	0.80	0.81	75
Weighted avg	0.78	0.77	0.78	75

Table 4. Sentiment model results

Replication of model framework to Reality+ ambit

In advancing Reality+'s vision for a universally harmonized transmedia platform with a consistent ethical goal for metaverse use, we tested our framework on another game within the Reality+ portfolio: Thunderbirds.

Operated by ITV in the Sandbox metaverse, Thunderbirds has its distinct contribution mechanism inherited from that platform. Testing with 102,000 Thunderbird Discord chats revealed similar results for intention, sentiment, and moderation models as with DWWA.

However, the contribution model lagged. Unlike DWWA, where series of messages were analyzed for context, the same sequential approach faltered for Thunderbirds. Discussions with the Thunderbird moderators attributed this to the community's less defined contribution patterns and cultural nuances. Yet, given the transactional nature of the Sandbox Metaverse, the model required significant adjustments. With the Thunderbird community already acquainted with SAND's game rewards, a pivot to community-focused contributions was deemed to be vital, however the overarching approach was considered apt for refining the

model with more curated data, so it was decided to implement this model and retrain it regularly based on data from the contributions going forward.

Impact on agency cost per wallet

Current costs without the new system per Wallet; The community team managed 250,000 wallets without the system with the app 30 moderators that worked part-time. From the founder, we understood the cost of moderation could be set to USD 50 per hour, and moderators worked half-time. Current Cost per Wallet per Day = Total Current Daily Agency Costs. Current Cost per Day were estimated as 30 x 8 x 50 / 2 = USD 6,000 in total agency cost per day, equal to USD 0,024 per wallet.

The new system incurs a daily cost of USD 5 for regular use, with the highest observed cost being USD 8 for analyzing 60,000 chats during the development, which took 300 hours, translating to USD 15,000 or an amortized daily cost of USD 41.10 over a year. Consequently, the total daily system expenditure is USD 66.10. With this system, the moderation team is able to efficiently manage 5,000,000 wallets at 0.00001322 USD each, marking a cost reduction of 1,815 times. Without the system, handling such a wallet volume would cost USD 120,000 daily. Hence, the system dynamics imply a 95% cost reduction on adoption.

Discussion

NFTs sparked a revolution in digital ownership, and blockchain-based business models, including DAOs, have found a product-market fit in the cultural economy, reaching from collectors to auctions to media and entertainment, including the metaverse (Messari, 2023).

The cultural economy is characterized by pronounced demand unpredictability, and the quest for tools to mitigate risk in decision-making is paramount (Towse & Hernández, 2020). As our experiment shows, AI can reduce agency costs. Still, there is also a risk of increased agency risk (Sidorova & Rafiee, 2019), but DLT/blockchain can forge a framework suitable for the governance and handling of the critical data that AI systems gather, preserve, and employ in this creator economy.

Our experiment successfully demonstrated the feasibility of implementing GPT-based models to sustain cultural production as an optimized internal control to improve moderation effort significantly as a community scales.

Combining blockchain’s affordances with generative AI for cultural production appears to be a promising and powerful mix, which can also make

reward practices more focused. While we have not yet seen the results of fully implementing the balanced contribution model in blockchain-based gaming, our findings suggest that the enforcement of a "proof of contribution" model can form a distinguishable and balanced subpopulation of socially networked non-kin with common "institutions of language" and rules to produce meaningfulness within a contextualized niche, which is strong enough to enable large-scale expansion, and, at the same time, avoid some unintended consequences of gaming.

GPT presents a step change to model development, where, based on processing time and model performance, the technology allowed us to create strong models in weeks that would otherwise have taken months with many resources in a traditional programming language setting.

Previous analysis of the Reality+ NFT marketplace revealed no material wash trading, so assuming one unique Discord ID represents one of the wallets connected to this NFT-based game, of which only 1,121 or app 1,4% access the Discord community, only 686, or less than one pct of the total number of wallets are relevant from a community-building and commercial perspective. Compared to financial data from Reality+, these results proved very realistic.

The results of the moderation modeling are quite promising and suggest that automated (mass) content moderation is feasible within the planning horizon of Reality+. However, even though the agency cost is reduced by 95 pct in this startup case, the results from our use case are not mass volume. It remains to be tested whether a cost-efficient model can be implemented in very large communities or whether it becomes prohibitively expensive to use a closed-source, open-access API service such as OpenAI.

Likewise, we opted to test OpenAI's GPT suite as a "quick win" to introduce advanced analytics to a young gaming community. Any of the LLMs in OpenAI's GPT 3.5 suite are likely much too advanced for the analytical challenges presented here, as the challenges are traditional classification problems, where less complex models perform. Yet, the project demonstrated to the moderator team how analytics could help them manage the community cultures during a hypergrowth phase. Evaluation feedback suggests that many other use cases will be moved forward, including incorporation of memory to the LLM through indexing and vectorizing the full histories behind the gaming characters to allow for faster and better support and knowledge management, as recently described in grey literature (IBM, 2023).

The contribution model findings underscore the potential of analytics in fostering and preserving shared cultural and ethical values across a broader ecosystem of interrelated communities, yet with some implementation effort, as the Thunderbird model endeavor suggested.

In our use case, a level of centralized control is required to manage customer brand IP. Yet, the mix of DLT and AI demonstrates the potential to implement a decentralized creator economy curated with intersubjectivity to reduce the risk of gaming a purely objective social algorithm.

Conclusion

By driving cooperation and coordination, traditional firms can indirectly enhance performance by creating a strong culture (Murphy et al., 2013). In this context, culture is not something you are but something you do as a network of live interactions striving towards a common objective. We can recognize the effects of a strong culture in successful enterprises and when it is toxic or missing.

Yet, increasingly, as we have seen in this case, large loosely tied communities develop online, where individuals work without traditional hierarchical restrictions and frequently with little to no exchange of direct economic value. Such networks create successful cultures and scale without top-down organizational steering. It has been suggested (Coyle, 2018), and also showcased in this paper, that such networked communities collaborate through an effective cultural code that exists beyond the control of managers, consisting of three elements: (1) signs of connection produce ties of identification and belonging, (2) mutual risk-taking behaviors foster trusting collaboration, and (3) narratives produce shared values and objectives.

Aligning to current research agendas in Blockchain, Metaverses, and DAOs, this paper explores culture from an evolutionary perspective in semi-decentralized web3-based gaming communities leveraging a novel blockchain-based business model that we call "proof of contribution," designed to reduce unintended consequences of addictive P2E gaming models in metaverses.

Using a case study approach, we asked the following research question (RQ): "*Are LLMs an option in identifying, nurturing, and sustaining culture in gaming communities going through hypergrowth?*"

We hypothesized that (1) pseudonymous actor intent can be predicted based on chat activity, (2) generative AI can make mass content moderation effective, (3) a common moral mission can be implemented effectively with advanced analytics, and (4) there is an unrealized automation potential that can significantly reduce moderation effort and compliance burden in managing community culture as web3 businesses scale. All hypotheses were confirmed, and we answered the RQ by presenting. (1) a pragmatic framework for rapid model development leveraging open-access LLMs to accelerate the use of analytics in an online community, (2) a number of industrial-ready trained model artefacts using OpenAI's API-based GPT-suite for decentralized communities wishing to nurture

their culture while scaling in a collaborative web3-based economy/metaverse construct, including (a) an intent classification model to predict pseudonymous community actor intent based on community behavior, (b) a moderation model to signal unwanted behavior for curation, (c) a contribution model to signal proof of desired contribution for further curation and reward based on a common moral mission to mitigate emerging risks in addictive blockchain-based gaming to reduce moderator workload and cost-effectively manage community culture in hypergrowth scenario, and finally (d) a community sentiment model.

While these functionalities are not new, the application in startup governance and the usage to manage group formation and production of culture in pseudonymous, decentralized communities planning for hypergrowth is, to the best of our knowledge, unique.

Key contributions of our framework to the field of gaming analytics and production include (i) deciphering intentions in pseudonymous economies: As communities evolve into new metaverse business models, the capability to identify the intent of pseudonymous actors becomes crucial, informing both economic interactions and cultural evolution; (ii) cultural moderation in digital economies: Our design pinpoints both toxic and desired behaviors. This nuanced understanding facilitates the curation of rewarding mechanisms aligned with a novel blockchain-based gaming contribution principle, ensuring cultural and economic alignment; (iii) sentiment analysis and cultural pulse: The ability to assess community sentiment provides real-time feedback on cultural shifts, an invaluable tool for both economic modeling and cultural preservation; and (iv) facilitating targeted growth with shared values: Our models strengthen the capacity to onboard specific persona groups, which significantly supports rapid growth with a consistent cultural mission, essential for sustainable economic activity in interconnected community ecosystems.

We contribute to the transmedia storytelling discourse with (i) the application of a contribution-based business model focused on collaboration, teamwork, and contribution around a common moral mission when transforming from web2 to web3 and metaverses, (ii) the governance of blockchain-based business models by introducing generative AI-based supported moderation policies, (iii) meta-sustainability by internalizing sustainability values at an individual level while developing a collective mindset that understands the importance of doing the right things the right.

Our findings underline the transformative potential of generative AI in cultural economics. Beyond improving gaming experiences or crafting immersive metaverse games, AI's capability to decode and shape gaming community cultures presents a new frontier in the innovative design of economic systems. Therefore, this research demonstrates the practical use of LLMs in managing digital

communities and significantly broadens the scope of their application in cultural economics.

Limitations and further work

We mainly utilized GPT3.5 for our research instead of the newer GPT4. Our priority was to enhance moderators' capabilities urgently, so we tested an API-based solution without exploring advanced systems like Google's BERT. Ideally, different models should be compared for accuracy on the same dataset, especially as datasets improve and require model retraining. Also, this study did not delve into gaming and metaverse infrastructures; Reality+ is still a startup developing its platform-agnostic metaverse strategy centered around Discord as relates community, and although the models proved highly useful in this stage of their growth journey, it remains to be tested if the models can perform cost-effectively as the volume increases. Additionally, the potential of GPT models in shaping decentralized business and algorithmic governance needs exploration, as and when Reality implements a financial model for contribution and decentralized ownership. Finally, our focus was on unique IDs for avatars in Discord. Still, a single individual might use multiple IDs, and verifying ID independence is crucial as the community grows to prevent system manipulation.

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