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Adapting Mintzberg's organizational theory to DeSci: the decentralized science pyramid framework

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To solve some of the challenges of traditional science, such as restricted access to funding, centralized governance, and siloed knowledge dissemination, decentralized science (DeSci) has emerged as a transformative approach facilitated by blockchain technology, Decentralized Autonomous Organizations (DAOs), and Web3. However, the emerging field of DeSci, faces several challenges, such as the absence of an organizational framework to describe its inherent complexities. This study introduces the Decentralized Science Pyramid Framework (DSPF), an innovative adaptation of Mintzberg's organizational structure, adapted to the unique demands and properties of DeSci. The DSPF delineates a structured model for DeSci projects that integrates technology, governance, community engagement, and application within a decentralized context. Through the introduction of the DSPF, this research highlights the operational dynamics of DeSci, focusing on the practical application of Mintzberg's theories to address real-world scientific challenges. The case study of VitaDAO, a decentralized autonomous organization exemplifying the core principles of DeSci, demonstrates the practical applicability of the DSPF. This study not only advances the academic discourse on DeSci but also offers practical insights for practitioners, innovators, and policymakers, marking a substantial step toward realizing the full potential of decentralized science.

KEYWORDS

decentralized science, blockchain technology, organizational theory, decentralized autonomous organizations, Mintzberg

1 Introduction

The emergence of decentralized science (DeSci), facilitated by advancements in blockchain technology, Decentralized Autonomous Organizations (DAOs), and Web3, marks a pivotal shift in the scientific research landscape. Situated at the intersection of organizational theory and decentralized organizations, this study seeks to address critical gaps in the understanding of the operational dynamics of decentralized structures within

Abbreviations: AUM, Assets Under Management; DAO, Decentralized Autonomous Organization; DeSci, Decentralized Science; DINO, Decentralized In Name Only; DLT, Distributed Ledger Technology; DSPF, Decentralized Science Pyramid Framework; IP-NFT, Intellectual Property Non-Fungible Token; LLCs, Limited Liability Companies; NFT, Non-Fungible Token.

scientific contexts. DeSci offers a promising approach to address some of the limitations of traditional research frameworks, characterized by centralized governance, restricted access to funding, and siloed knowledge dissemination (Weidener and Spreckelsen, 2024). However, the novel field of DeSci faces challenges such as the absence of a robust, universally accepted organizational framework that can address its inherent complexities and optimize its transformative capabilities. This study aims to bridge this critical gap by establishing a comprehensive theoretical foundation tailored to the unique demands and opportunities of DeSci.

Existing scientific publications focusing on the DeSci infrastructure are limited and often operate without a comprehensive theoretical foundation; thus, a structured approach essential for effectively navigating and optimizing the DeSci ecosystem is lacking (Ding et al., 2022; Mayr, 2022). A recent publication presented a six-layer reference model for DeSci, delineating the ecosystem into protocol, governance, incentive, organizational, operational, and application layers. This model underscores the multifaceted nature of DeSci, highlighting the critical areas of innovation and collaboration that decentralized science enables from the foundational protocol layer that ensures secure and transparent operations to the application layer, where the practical implications of DeSci unfold (Ding et al., 2022).

Similarly, another publication offered an insightful analysis of the 'DeSci Stack', categorizing it into three core layers: infrastructure, middleware, and applications (Mayr, 2022). The publication emphasizes the significance of middleware as a catalyst for innovation, facilitating the development of applications by providing an abstraction layer over the generalized infrastructure. This perspective highlights the pivotal role of technology in supporting DeSci applications, from investment DAOs to marketplaces for IP transactions (Mayr, 2022).

DAOs introduce unique organizational and management challenges rooted in their decentralized structures (Law, 2021). Operating without centralized leadership, DAOs employ token-based governance systems and distribute decision-making authority among the stakeholders. This model fosters inclusivity and transparency, enabling participants to vote on proposals, allocate resources, and collaboratively shape strategic objectives (Law, 2021). However, as organizations scale, this decentralized model can result in slower consensus-building, misaligned strategies, and difficulties in managing diverse participant interests (Schneider et al., 2022). The pseudonymity of DAO members further complicates accountability by limiting the transparency of individual contributions and enforcing collective goals (Napieralska and Kepczynski, 2024). Additionally, reliance on smart contracts for operational processes, while enhancing efficiency, introduces vulnerabilities, as bugs or security risks can disrupt core functions. Coordination among globally distributed members, coupled with the absence of a formal hierarchy, often requires innovative approaches for conflict resolution, long-term planning, and decision-making (Law, 2021; Ballandies et al., 2024). These complexities underscore the need for structured frameworks that accommodate the distinct governance and operational dynamics of DAOs, while preserving their innovative potential. Mintzberg's organizational framework offers a robust theoretical lens for analyzing and addressing these challenges (Mintzberg, 1979). Its emphasis on interconnectedness and coordination mechanisms, such as mutual adjustment and standardization, is particularly relevant in decentralized settings. By adapting Mintzberg's framework to the DeSci context, this study provides a systematic approach for navigating the structural and operational intricacies of DAOs, bridging critical gaps in both theory and practice.

For instance, Mintzberg's Organizational Structures, with its detailed categorization of organizational parts and mechanisms, offer a theoretical approach through which the decentralized, often complex, interactions within DeSci can be more systematically analyzed and understood (Mintzberg, 1979). By integrating such organizational theories, the mechanisms of coordination, decision-making, and innovation that are intrinsic to DeSci can be conceptualized, thereby offering a more nuanced and effective framework for its development and evaluation.

Recognizing this gap, this study aims to adapt Mintzberg's organizational structure–a well-established theoretical framework in the realm of organizational theory–to the context of DeSci. Mintzberg's model, with its emphasis on the interaction between the strategic apex, middle line, operating core, technostructure, and support staff, provides a nuanced perspective on organizational design and functionality. By applying this model to DeSci, this study aims to highlight the operational dynamics of DeSci initiatives and projects, highlighting how various elements of Mintzberg's framework manifest in a decentralized setting. This research contributes to advancing academic discourse in both organizational theory and decentralized systems by positioning the Decentralized Science Pyramid Framework (DSPF) at the intersection of these domains. The DSPF not only provides a theoretically robust model, but also offers actionable insights for practitioners, policymakers, and innovators, addressing the pressing need for structured approaches in the evolving DeSci ecosystem.

1.1 Hypothesis

This study hypothesizes that adapting Mintzberg's organizational framework into the Decentralized Science Pyramid Framework (DSPF) provides a comprehensive and practical model for mapping Decentralized Autonomous Organizations in DeSci (DeSci-DAOs). Specifically:

- The DSPF captures the dynamics of decentralized governance, collaboration, and innovation in DeSci-DAOs, offering actionable insights and practical strategies to enhance their structural and operational effectiveness.

2 Methodology

This study employed a dual approach to address the structural and operational challenges of DeSci. It combines the theoretical adaptation of Mintzberg's organizational framework into the Decentralized Science Pyramid Framework (DSPF) with a practical demonstration of the framework's applicability through the case study of VitaDAO, the first and arguably most successful DeSci-DAO (Weidener and Spreckelsen, 2024). These complementary components ensure that the DSPF is both

theoretically grounded and practically relevant, providing a robust model for understanding and optimizing decentralized governance, collaboration, and innovation within DeSci.

2.1 Model selection and author expertise

The selection of Mintzberg's organizational theory as the basis for this adaptation was guided by the authors' deep domain expertise and active involvement in the DeSci ecosystem. Given the emerging nature of DeSci, an area of rapid development since the claimed coinage of the term in 2021, domain expertise provides critical insights into its unique structural and operational challenges (Koepsell, 2022). All co-authors are actively engaged in DeSci projects, with two co-authors holding leading roles within the ecosystem, such as serving as a core member or working group lead in DeSci-DAOs. This involvement provides direct exposure to the governance and operational dynamics of functional DAOs, ensuring that the framework is grounded in practical reality.

The expertise and background of the authors also guided the identification and selection of an organizational model or framework suitable for the decentralized nature of DeSci, ensuring that it reflects the current DeSci-DAO ecosystem. A literature review of well-recognized organizational models in both traditional and decentralized contexts has led to the evaluation of several frameworks. Systems Theory, for example, offers a holistic perspective on the interrelations of organizational components, but lacks specific mechanisms to analyze operational dynamics, such as governance and decision-making, which are central to DAOs in DeSci (Von Bertalanffy, 1972). Similarly, Network Theory excels in examining the structure and interactions of complex networks, such as those within decentralized systems, but does not address internal organizational structures or governance processes (Barabási, 2002; Barabási et al., 2002). The Resource-Based View focuses on leveraging internal resources for competitive advantage, yet it does not sufficiently account for decentralized governance or structural complexities within the DeSci ecosystem (Barney, 1991; Barney, 2001). Actor-Network Theory aligns with the interplay of human and technological actors, such as blockchain and governance tools, but lacks the structural details and practical mechanisms required to model operational frameworks effectively (Latour, 1996).

Mintzberg's organizational framework was ultimately chosen for its emphasis on interconnectedness and coordination mechanisms, such as mutual adjustment and standardization, which closely align with the decentralized and collaborative ethos of DeSci. By categorizing organizational components such as the strategic apex, operating core, technostructure, and governance structures, Mintzberg's framework provides a robust perspective for analyzing how these elements interact dynamically within decentralized organizations. Its focus on coordination mechanisms offers a critical advantage for understanding and optimizing decentralized governance and operational processes central to DeSci, where mutual adjustment fosters flexibility and innovation, and standardization ensures stability and coherence. Moreover, Mintzberg's adaptability across both hierarchical and non-traditional organizational settings makes it particularly suitable for the evolving ecosystem of DeSci-DAOs, where successful operations rely heavily on seamless interaction of governance, collaboration, and innovation.

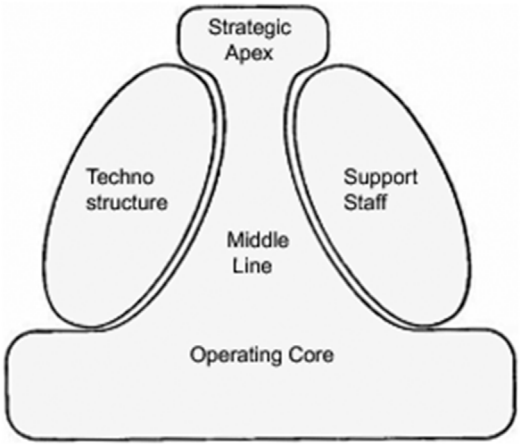

FIGURE 1
The five elements of Mintzberg's organizational model (Mintzberg, 1979).

2.2 Case study selection

VitaDAO was chosen not only for its status as the first DeSci DAO but also for its significant influence on the ecosystem. The organizational model employed by VitaDAO has served as a reference for subsequent DAOs, including ValleyDAO, AthenaDAO, CryoDAO, PsyDAO, HairDAO, and CerebrumDAO (ValleyDAO, 2023; Magierski et al., 2024; Minquini and Santos Silva, 2023; PsyDAO, 2024b; CryoDAO, 2023; Bakst and Verbinnen, 2022). Although these DAOs represent only a subset of the broader DeSci ecosystem, their shared governance structures and operational models highlight the relevance of the framework to a substantial portion of functional DAOs. This selection is further supported by a preceding ecosystem analysis, which indicated that only a limited number of DeSci DAOs are functional, based on criteria such as the issuance of governance tokens and active community-based governance processes (Weidener and Spreckelsen, 2024).

3 Theoretical background: Mintzberg's organizational theory

The conceptual underpinnings of organizational design and structure, which have been extensively explored within the field of management sciences, have led to the development of various models that explore the complexities inherent in organizational dynamics. Henry Mintzberg's theory of organizational structures, first introduced in 1979, has emerged as an important framework (Mintzberg, 1979). It provides a comprehensive approach through which the structures of organizations can be analyzed, offering invaluable insights into the distribution of responsibilities and information flow within organizations. Mintzberg's model, based on empirical observations of organizational operations, categorizes an organization into five essential components: Operating Core, the Middle Line, the Technostructure, the Support Staff, and the Strategic Apex. This structure is key to comprehending how

responsibilities are distributed and how information circulates within an organization, thus providing a detailed perspective on organizational design (Mintzberg, 1979). An overview of the five elements of Mintzberg's organizational model is shown in Figure 1.

The foundation of the organization is the Operating Core, where primary activities related to the production of goods and services are executed. This segment involves employees who are directly engaged in manufacturing, services, and other central operations that contribute directly to the organization's value creation. The effectiveness of the Operating Core's production is critical to the organization's success, significantly affecting the quality and delivery of the organization's outputs.

The Middle Line acts as a bridge between the Operating Core and the Strategic Apex, facilitating the translation of strategic directives into practical actions. This layer includes managers at various levels who oversee operational activities, ensuring that they align with the organization's strategic goals. The Middle Line is pivotal in upholding organizational coherence and enabling communication throughout the organizational hierarchy.

In parallel with the Middle Line, the Technostructure is charged with designing, implementing, and maintaining systems and processes that govern and standardize the organization's operations. This includes specialists in planning, quality control, and process improvement, whose efforts are crucial for ensuring operational efficiency and uniformity through standardized work processes and technical guidance.

The Support Staff provides essential support services to the organization, facilitating operations without directly engaging in the main workflow. This encompasses departments such as human resources, IT support, and legal services, which are vital for maintaining the operational capabilities of the organization and allowing core activities to proceed smoothly.

Finally, the Strategic Apex is responsible for the organization's strategic positioning, ensuring the organization's adherence to its strategy and creating an organization that can achieve its overarching objectives. The Strategic Apex refers to and includes senior management and executive leadership tasked with setting strategic directions, making key decisions, organizing production via the appropriate Technostructure and upholding the organization's credibility with external stakeholders. The Strategic Apex is essential for navigating external environmental complexities and steering the organization towards its strategic aims.

Mintzberg's model emphasizes the interplay between these elements, underscoring the necessity of their integrated functioning for optimal organizational performance. By detailing the roles and interconnections of these essential parts, Mintzberg's framework offers deep insights into the impact of organizational design on efficiency and adaptability, serving as a key tool for analyzing organizational structures and identifying areas for targeted improvements.

4 Mintzberg's organizational structures in decentralized science: an adaptation

Adapting Mintzberg's organizational structure to the decentralized setting of DeSci requires a nuanced understanding of both the original framework and unique dynamics of decentralized science. This study proposes the 'Decentralized Science Pyramid Framework' (DSPF) as an adaptation of Mintzberg's organizational model for DeSci.

The adaptation of Mintzberg's organizational structures in this study is grounded in both the active participation of researchers in various DeSci initiatives and organizations (including DAOs) and an extensive review of the relevant literature in preceding research1. This combination of practical engagement and scholarly analysis can be considered a form of domain expertise, ensuring that the DSPF reflects both the theoretical rigor and practical realities of DeSci. Each section of this framework includes practical suggestions for applying the model to existing DAOs within the DeSci ecosystem, bridging theory, and practice.

4.1 Community as the operating core

In the DSPF, the Community is positioned as the foundational layer, paralleling Mintzberg's concept of the Operating Core. The community in DeSci plays a critical role in driving the primary activities of decentralized science, similar to how the Operating Core in traditional organizations is responsible for producing goods and services.

The community in DeSci is a collective body of researchers, developers, contributors, and participants actively engaged in the ideation, development, and execution of scientific projects. This collective is not just involved in core operations; they are operations. Unlike traditional organizational models, where the Operating Core consists of well-defined roles within a clear hierarchy, the DeSci community is characterized by fluidity and openness. Members of the community contribute to the ecosystem in various capacities, often crossing traditional role boundaries driven by their expertise, interests, and the evolving needs of the projects.

In DeSci, the community functions as the engine of scientific progress, embodying a decentralized ethos by democratizing participation in research and development. The community's engagement ranges from conducting research and developing new technologies to proposing new ideas and collaborating with existing projects. This bottom-up approach ensures that the direction and output of DeSci initiatives are directly shaped by those that actively contribute to the scientific process. The decentralized nature of DeSci allows for a broad spectrum of participation, where contributions can come from a wide array of individuals from established scientists and academic researchers to hobbyists and citizen scientists. The fluid mode of operations furthermore allows for contributions to varying extents and with different time scopes. Individuals can be part of the Operating Core as much and as little as their expertise and personal capacity allows. A mix of one-time, irregular and regular contributors fosters an open and diverse environment and lowers the risk of confirmation biases within the organization. This diversity within the Operating Core is a strength of the DeSci ecosystem, fostering innovation and allowing the emergence of groundbreaking ideas that might not surface in more centralized, traditional scientific settings.

The community's role as the Operating Core is further enhanced by decentralized tools and technologies that support their activities. The community uses decentralized technologies, including blockchain, for transparent funding, intellectual property

management, and communication tools to coordinate efforts, ensuring that their work is conducted openly and efficiently. These technologies empower the community to operate autonomously, coordinate efforts, and share results, thereby ensuring that the scientific process remains open and accessible. Within DSPF, the community does not operate in isolation. It interacts continuously with the other layers of the framework—namely, the Technology (resembling the Technostructure), Organizational Structures (resembling the Middle Line), and Governance—each of which supports and enhances the community's ability to function as the Operating Core. These interactions ensure that the community's contributions are not only impactful, but also aligned with the broader strategic objectives of the DeSci initiative.

The adaptation of Mintzberg's Operating Core to represent the community underscores the shift from hierarchical to decentralized organizational models. In traditional organizations, the Operating Core is often directed by the Strategic Apex through the Middle Line. In contrast, within DeSci, the community as the Operating Core is self-directed, with governance and organizational structures enabling collective decision making and coordination rather than top-down directives. Autonomy is a defining feature of the DeSci ecosystem, allowing for rapid iteration, flexible responses to challenges, and a high degree of ownership among contributors. The pivotal role of the community in DeSci reflects a broader paradigm shift in how scientific research is conducted and shared. By positioning the community as the Operating Core, the DSPF highlights the centrality of collaborative, decentralized efforts to drive scientific innovation forward. This structure not only democratizes the scientific process, but also ensures that the outputs of DeSci are reflective of a wide range of perspectives and expertise, ultimately contributing to a more robust and diverse scientific landscape.

4.1.1 Suggestions for practical application

- Incentivizing Contributions
  - Establish decentralized reward systems to recognize and incentivize contributions, regardless of frequency or scale (e.g., one-time contributions vs. regular involvement).
  - Develop tiered reputation systems where contributors earn tokens or badges based on their expertise, activity, and impact, fostering a meritocratic and inclusive environment.
- Enhancing Engagement
  - Facilitate onboarding of new contributors through automated tools like Discord bots, assigning roles based on skills and interests to streamline their integration into relevant projects.
  - Organize regular hackathons or brainstorming sessions to encourage cross-disciplinary collaboration and align contributors around shared goals.
- Ensuring Transparent Collaboration
  - Leverage blockchain-enabled tools for transparent documentation and attribution of intellectual property, ensuring contributors receive credit and recognition for their work.
  - Adopt decentralized project management tools (e.g., Notion or Asana integrated with DAOs) to enhance transparency, accountability, and alignment across the community.
- Mitigating Risks of Fragmentation and Bias
  - Regularly facilitate community-wide discussions and workshops to align diverse perspectives and maintain coherence in strategic objectives.
  - Implement periodic audits of community activities to ensure balanced representation and mitigate risks of dominance by specific subgroups.

4.2 The core layers: technology, organizational structures and governance

In Mintzberg's schema, the Technostructure, Middle Line, and Support Staff form distinct components within an organization's structure. The DSPF, reflecting DeSci's bottom-up, community-driven nature, re-conceptualizes these elements as an integrated Core Layer. This integration marks a departure from Mintzberg's top-down hierarchy, reimagining these components within the context of decentralized science, where strategic ideation originates from the collective rather than a central command.

4.2.1 Technology and its parallel to Mintzberg's technostructure

As the first element of the core layer of the DSPF, Technology finds its organizational parallel in Mintzberg's concept of the Technostructure. In Mintzberg's framework, the Technostructure is integral to an organization responsible for designing, implementing, and maintaining systems that standardize and optimize its operations. It encompasses specialists and analysts who develop the methodologies, processes, and tools that underpin the efficient execution of an organization's core activities. This alignment with the Technostructure underscores the pivotal role of technology in shaping the operational and strategic capabilities of the DeSci initiatives.

In this context, technology transcends the traditional boundaries of supporting operations. It serves as the foundation upon which decentralized science projects are built and operated. Technologies in DeSci do not support the organizations, but rather define them. These include, for example, Distributed Ledger Technology (DLT, a type of digital database that is consensually shared and synchronized across multiple sites, institutions, or geographies, allowing transactions to have public "witnesses" and ensuring transparency and immutability), governance tokens (digital assets that grant holders the right to vote on decisions within a Decentralized Autonomous Organization, impacting project directions and rules, which is essential for decentralized governance and collective decision-making), Non-Fungible Tokens (NFTs, digital assets that represent ownership of a unique item or piece of content on the blockchain, ensuring its scarcity and provenance, which is crucial for tracking and verifying ownership and authenticity), and Intellectual Property Non-Fungible Tokens (IP-NFTs, which tokenize intellectual property rights, allowing for the secure and transparent sale, licensing, or transfer of IP, thereby facilitating efficient and trustworthy IP management).

Furthermore, the core element of technology extends to the chosen settlement layer for transactions (e.g., Ethereum, a decentralized blockchain platform that enables the creation and execution of smart contracts and decentralized applications,

providing a trustless environment for transactions and interactions); decentralized applications (dApps, software applications that run on a decentralized network, typically using blockchain technology, and operate autonomously without central authority, which is essential for maintaining decentralization and reducing reliance on central entities); smart contract functionality (self-executing contracts in which the terms of agreement are directly written into code, automatically enforcing and executing the terms, thereby ensuring trust and eliminating the need for intermediaries); and potential scaling solutions (e.g., zero-knowledge proofs and cryptographic techniques that allow one party to prove that a statement is true without revealing any information beyond the validity of the statement, enhancing privacy and security). These technological components are not just tools, but are the essence of DeSci, enabling open, decentralized, transparent, and secure collaboration and innovation worldwide. The incorporation of scaling solutions, such as rollups or sidechains, privacy technologies, and decentralized storage solutions, further exemplifies the comprehensive and foundational nature of technology within DeSci. Without these elements, maintaining the integrity, efficiency, and trust required for decentralized scientific collaboration and innovation would be challenging.

The adaptation of Mintzberg's Technostructure in DeSci is necessitated by the decentralized setting of these initiatives. In traditional organizations, Technostructure shapes the workflow and ensures efficiency through standardization and control mechanisms put in place by senior management. It includes elements such as planning, quality control, and process improvement, which are supported by a legal framework that establishes trust through mandatory governance rules, liability of decision-makers, and compliance requirements. This legal setup creates a foundation for trust for internal and external stakeholders, ensuring that operations are conducted within a regulated environment that holds individuals and entities accountable. However, in DeSci, technology performs more than streamlined operations; it defines the parameters of collaboration, governance, and innovation. Trust in DeSci is established not mainly through traditional legal frameworks but through advanced technological mechanisms that enable a shift from centralized authority and centralized decision-making to a community-driven, distributed and consensus-building approach within a computerized governance-framework. Through token voting and smart contracts, technologically governed organizations (e.g., DAOs) are foundational to DeSci initiatives. Given the fundamental role of technology in DeSci, which is inherently connected to ideation, the element of technology extends from the core to the foundational layer, embedding computerized trust directly into operational and governance processes. In the decentralized context of DeSci, trust is built through protocols, smart contracts, and open source reviews. Protocols and smart contracts automate and enforce compliance, thereby reducing the need for traditional intermediaries and legal enforcement. Moreover, the open-source nature of these technologies allows for continuous scrutiny and improvement of the community. Anyone can inspect, audit, and propose changes to the code, ensuring that the technostructure remains robust and secure. Communal oversight enhances trust and reliability as the collective intelligence of the community identifies and addresses vulnerabilities.

Furthermore, the integration of technologies such as artificial intelligence, communication platforms (e.g., Discord; https://discord.com; Telegram), and collaboration tools (e.g., Notion, https://notion.so; Asana, https://asana.com; ClickUp, https://clickup.com) within DSPF's core layer illustrates the expansive role of technology in DeSci. It not only facilitates the operational and legal aspects of projects but also fosters community engagement and collaboration, thereby embodying both the structural and social dimensions of decentralized science. The adaptation of Mintzberg's Technostructure reflects the critical role of technological innovation and implementation in the DeSci ecosystem. This underscores the necessity for a robust, flexible, and efficient technological infrastructure that supports decentralized operations and governance, facilitating an open, collaborative ethos that is central to DeSci.

4.2.1.1 Suggestions for practical application

- Incentivizing Contributions
  - Implement smart contracts to automate governance and decentralized operations.
  - Adopt open-source protocols to enable community-driven audits and continuous code improvement, enhancing security and reliability.
- Optimizing Technological Infrastructure
  - Use layer-2 scaling technologies, such as rollups or sidechains, to address transaction bottlenecks and improve blockchain efficiency.
  - Employ interoperable blockchains to balance scalability, security, and cost-effectiveness across decentralized applications.
- Enhancing Decentralized Collaboration
  - Utilize platforms like Discord and Telegram for real-time communication and collaboration among community members.
  - Implement tools like Snapshot for token-based voting to ensure inclusive and transparent decision-making processes.

4.2.2 Organizational structures and its correlation to Mintzberg's middle line

In the DSPF, Organizational Structures correlate directly with Mintzberg's concept of the Middle Line. These structures are essential for facilitating the coordination and communication necessary for the community (Mintzberg's Operating Core) to achieve their objectives. This adaptation reflects the decentralized, dynamic nature of DeSci, in which traditional hierarchical management is replaced by more distributed, flexible, and open forms of governance.

In Mintzberg's framework, the Middle Line serves as a crucial link between the Strategic Apex and the Operating Core, ensuring that strategic directives are effectively translated into operational activities. In the context of DeSci, Organizational Structures fulfill a similar role by enabling the community to self-organize into functional groups, such as DAOs and associated working groups, that can focus on specific tasks or projects. These structures allow the community to channel its collective efforts towards the achievement of shared goals, whether they involve research, development, governance, or other key activities within a decentralized ecosystem. Organizational Structures

within the DSPF are designed to support fluid and dynamic coordination across multiple levels and entities, mirroring the connective function of the Middle Line, but within a more networked and less hierarchical context. These structures enable the community to form specialized groups that address different aspects of a project, such as technical development, governance, communication, and outreach, ensuring that all necessary functions are covered without relying on centralized control.

The decentralized nature of DeSci introduces unique challenges that necessitate innovative organizational models. In many cases, DeSci initiatives may operate within legal environments that do not fully support decentralization, leading to the emergence of entities that are 'Decentralized In Name Only' (DINOs) (Song, 2021). These entities often retain centralized elements owing to legal and regulatory constraints, which can undermine the decentralized ethos of the projects. For instance, the need to comply with existing legal standards often requires the establishment of formal legally recognized entities, such as limited liability companies (LLCs) or non-profit foundations that interface with traditional frameworks while attempting to maintain a decentralized operational structure (Bayern et al., 2017). A solid legal setup with clearly distributed responsibilities is essential to shield for individuals from unnecessary liability risk, especially for small and irregular contributors. This dual focus on decentralized innovation and compliance with existing legal norms creates a complex hybrid organizational model within DeSci. Organizational Structures must, therefore, be designed to navigate these challenges, ensuring that the community can operate effectively while adhering to the necessary legal and regulatory requirements. This often involves the creation of governance frameworks that allow decentralized decision making within the constraints imposed by traditional legal systems.

Organizational Structures in the DSPF play a critical role in maintaining the coherence and effectiveness of decentralized projects. They provide a framework within which the community can organize itself, establish working groups, and allocate responsibilities. These structures also facilitate the communication and coordination necessary to align the community's activities with the project's broader strategic goals. By enabling the community to form and dissolve working groups as needed, Organizational Structures ensure that DeSci initiatives remain adaptable and responsive to changing conditions and new opportunities. This flexibility is essential in a decentralized environment where traditional top-down management is absent, and the success of a project depends on the community's ability to self-organize and collaborate effectively. Moreover, the inclusion of legal entities within this layer underscores the pragmatic need for DeSci projects to interface with the traditional legal environments and to mitigate liability risks for contributors. This often necessitates the formation of hybrid organizational models that balance decentralized governance with legal requirements for accountability and compliance. While these models may introduce elements of centralization, they are critical for ensuring the long-term viability of DeSci projects in the current legal landscape.

4.2.2.1 Suggestions for practical application

- Enhancing Coordination
  - Establish self-organizing working groups focused on specific project areas, such as governance, technical development, and community outreach.
  - Create processes for forming and dissolving working groups based on project needs, ensuring flexibility and responsiveness to changing conditions.
- Balancing Decentralization and Compliance
  - Incorporate legally recognized entities, such as non-profits or LLCs, to manage external obligations while preserving decentralized operational structures.
  - Distribute responsibilities clearly within organizational structures to shield contributors, especially small or irregular ones, from unnecessary liability.
- Strengthening Strategic Alignment
  - Use flexible organizational models that allow cross-functional collaboration between working groups to align activities with broader strategic objectives.
  - Facilitate regular inter-group communication sessions to ensure coherence and shared understanding of goals.

4.2.3 Governance as a unique adaptation of Mintzberg's support staff

In Mintzberg's organizational framework, the Support Staff is responsible for providing specialized services that enable the core functions of the organization, such as human resources, legal services, and administrative support. These roles are typically centralized and function to maintain the organization's stability and compliance with external regulations. However, in the DSPF, this concept is redefined as Governance to reflect the decentralized and community-driven nature of DeSci initiatives. Governance in DeSci is not a peripheral support function, but a central mechanism that empowers the community to self-regulate, coordinate, and maintain the decentralized ethos that is foundational to these initiatives. Governance is enabled by the two other elements of the core layer (Technology and Organizational structures) and at the same time empowers and establishes the community as Operating Core of DeSci initiatives.

Governance within the DSPF represents the mechanisms, processes, and structures employed by the community to coordinate, regulate, and manage decentralized scientific projects. Unlike traditional Support Staff, which operate under centralized control, Governance in DeSci is decentralized and participatory control. Through Governance, the community enforces rules, makes collective decisions, and ensures that the initiative's decentralized nature is maintained. Governance frameworks typically involve DAOs that use smart contracts and token-based voting systems to facilitate decision making, coordination and resource allocation. These DAOs serve as primary governance structures, enabling all participants to contribute to the governance process in a transparent and equitable manner. Through these mechanisms, Governance ensures that the community's activities align with the strategic goals of the project while also maintaining the flexibility and adaptability required in a decentralized environment.

Unlike traditional Support Staff, which often operate behind the scenes, Governance in DeSci is inherently participatory and visible. Every community member has the potential to contribute to the governance process by proposing new initiatives, voting on key issues, or engaging in discussions that shape the project's trajectory. This participatory model is crucial for maintaining the decentralized nature of DeSci, where the community is both the driver and regulator of its activities. Moreover, Governance must navigate

the intersection between decentralized operations and traditional legal and regulatory frameworks. This often requires the establishment of hybrid structures, such as non-profit foundations or limited liability companies, which can interface with existing legal systems while supporting decentralized decision making. These hybrid models allow DeSci initiatives to comply with legal requirements without compromising their decentralized principles.

The governance process and the community participation within DeSci and decentralized organizations is fueled by 'Tokenomics'. Tokenomics substitute the hierarchies and human resource functions of traditional organizations with novel incentive structures based on cryptographic tokens (Lamberty et al., 2023). Within tokenomic-enabled Governance structures Token can represent not only financial value, but also represent reputation, work contributions, copyrights or voting rights. Tokens not only enable different forms of meritocratic governance, but also serve as an additional funding method for DeSci projects. Community governed token treasuries DeSci initiatives can award project tokens for valuable contributions, voting participation or any other activity. This increases the overall funding power of DeSci initiatives beyond the financial capital raised by including potential contributions. Good tokenomics of a project incentive and reward valuable contributions directly through the distribution of new tokens as well as through the possible value gains of existing tokens. Furthermore, tokenomics not only foster collaboration and increase the resources available to DeSci projects, but they also enable governance participation from all parts of society. Voting power can not only be bought, but also be earned, incentivizing, and enabling participation regardless of financial constraints of individuals.

In this novel adaptation, governance replaces the traditional role of Support Staff by providing the necessary regulatory and coordination functions in a decentralized context. Tokenomics increase the resources of initiatives while fostering diverse participation. This ensures that DeSci initiatives operate efficiently, remain compliant with relevant legal standards, and stay true to their decentralized ethos. Governance is thus a fundamental component of the DSPF that is integral to the successful implementation and sustainability of decentralized science projects.

4.2.3.1 Suggestions for practical application

- Facilitating Transparent Decision-Making
  - Use token-based voting systems to ensure equitable participation in governance processes, allowing contributors to propose, discuss, and vote on initiatives.
  - Integrate smart contracts to automate enforcement of governance rules and streamline decision-making.
- Encouraging Community Participation
  - Develop incentive structures that reward contributions to governance, such as active voting or proposing initiatives, using tokens or reputation systems.
  - Provide open-access platforms for discussions (e.g., forums and community calls) to ensure inclusivity and transparency in governance activities.
- Establish Efficient Resource Allocation
  - Establish dynamic token treasuries governed by transparent, community-driven mechanisms to prioritize high-impact projects and reward contributors based on measurable outcomes.
  - Design tokenomics that align resource allocation with strategic goals, such as incentivizing milestone-based funding and rewarding long-term commitment through vesting schedules or stacking mechanisms.

4.3 Application as a reflection of Mintzberg's strategic apex

In the DSPF, Mintzberg's concept of the Strategic Apex is reimagined as the Application, which represents the practical realization of DeSci projects. This layer embodies the culmination of ideas, technologies, organizational structures, and community engagement, converging to address specific scientific inquiries, challenges, or objectives. The Application serves as the point where the innovative potential of DeSci is actualized, translating collective efforts into tangible outcomes. These outcomes range from groundbreaking biotechnological research and the development of open-source pharmaceuticals to novel approaches in scientific collaboration, all underpinned by the principles of open collaboration and transparency that are central to DeSci.

In traditional organizations, the Strategic Apex is responsible for top-down management, coordinating activities that drive revenue and increase company value, often reflected in the share prices of publicly traded companies. However, DeSci operates using different paradigms. Rather than relying on a centralized leadership structure to generate revenue, DeSci initiatives depend primarily on community contributions. In this context, the "currency" within the DeSci ecosystem is not solely traditional financial capital but includes a combination of factors such as the value accrual of governance tokens, the volume and quality of community contributions, the project's reach, and the Assets Under Management (AUM). This difference raises critical questions about the optimal organizational structure for DeSci projects and the potential need for changes to align better with traditional revenue generation models. Unlike traditional companies, where financial performance is often the primary metric of success, DeSci projects may need to consider how to balance their decentralized ethos with the practical realities of sustaining and scaling their initiatives.

To align more closely with revenue generation, DeSci projects may need to adopt additional strategies and structures that emphasize project success metrics and financial returns. This could involve integrating traditional financial oversight and performance-tracking mechanisms into a decentralized framework, ensuring that the outcomes of DeSci projects translate into tangible values. For instance, this may include the development of products and services that can be monetized either through offerings to DAO token holders or through external markets, thus providing revenue streams that support the long-term sustainability of the DAO and its broader mission. However, the decision to integrate revenue-generating mechanisms must be carefully weighed against their potential impact on the decentralized nature of these projects. The long-term goals of each DAO play a crucial role in determining whether they should maintain their current structure or adapt it to incorporate more traditional

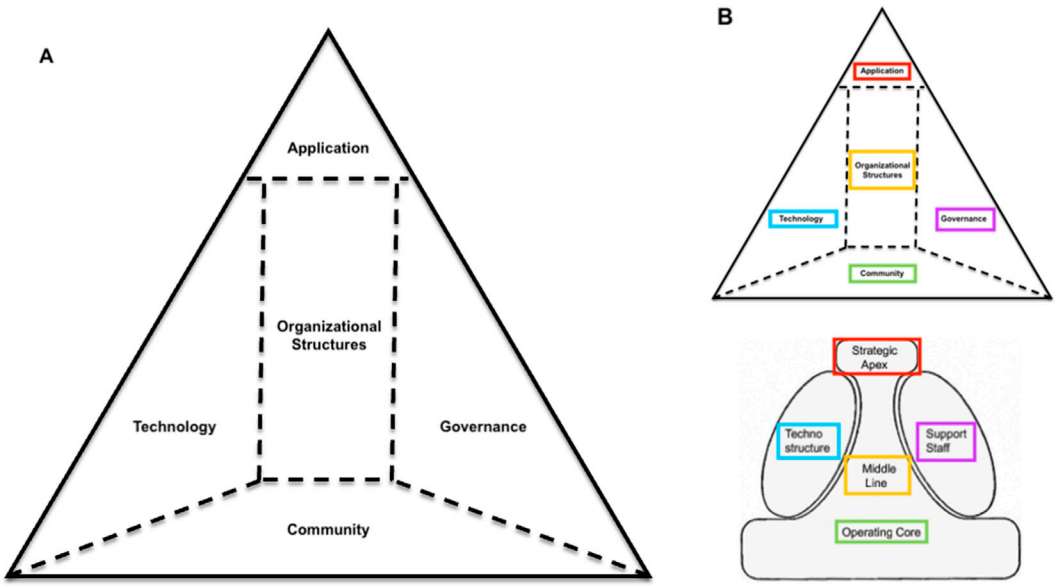

FIGURE 2
(A) The Decentralized Science Pyramid Framework (DSPF) as an adaptation of Mintzberg's Organizational Theory. **(B)** Color-coded comparison of the DSPF with Mintzberg's Organizational model (Mintzberg, 1979).

financial strategies. A hybrid approach that balances community-driven engagement with strategic financial oversight offers the most sustainable forward path. This approach would allow DeSci initiatives to preserve their decentralized ethos, while incorporating elements of the DSPF to facilitate both reach and revenue generation, thereby ensuring the continued advancement and impact of DeSci.

Ultimately, the Application layer in the DSPF reflects the strategic realization of DeSci's mission, where the collaborative efforts of the community are transformed into concrete scientific contributions. By considering the integration of traditional financial structures within a decentralized framework, DeSci projects can enhance their ability to achieve long-term sustainability without compromising the principles of openness and collaboration that define DeSci. An illustration of the DSPF is shown in Figure 2A. Figure 2B represents a color-coded comparison of the DSPF with Mintzberg's organizational model.

While Figure 2 provides a high-level overview of the DSPF and its adaptation to Mintzberg's Organizational Theory, it is important to acknowledge the specific interactions and dynamics that drive the framework's effectiveness and provide practical value for organizations in DeSci. A more detailed visualization is necessary to illustrate how each component of the DSPF - Community, Technology, Organizational Structures, Governance, and Application - interacts in practice. Figure 3 represents a specification of the DSPF, where each high-level element of the DSPF is exemplified by more specific, practical components that demonstrate their real-world application in DeSci.

4.3.1 Suggestions for practical application

- Enhancing Sustainability
  - Develop hybrid funding models that combine traditional revenue streams (e.g., monetized services) with decentralized token-based treasuries to support long-term viability.
  - Implement milestone-based funding mechanisms to align resource allocation with project progress and deliverables.
- Strengthening Community Contributions
  - Encourage the co-creation of products or services by community members through open innovation challenges, ensuring alignment with community priorities.
  - Leverage governance tokens to incentivize active participation in shaping project directions and outcomes.
- Aligning Strategic Objectives
  - Define clear success metrics, such as token value accrual, community growth, or knowledge dissemination, to track the fulfillment of the project's mission.
  - Establish regular evaluation frameworks to reassess the alignment of outcomes with the project's strategic goals and adapt as needed.

5 Applying the decentralized science pyramid framework: a case study

The DSPF represents a novel approach to understanding and structuring DeSci projects. By applying this framework, the complexities and innovations inherent in DeSci initiatives can be explored and appreciated. This case study aims to apply the DSPF through an in-depth examination of VitaDAO, a DAO that exemplifies the core principles of DeSci by fostering community-governed and decentralized drug development and intellectual property management (Golato and Kohlhaas, 2021). VitaDAO's mission to accelerate research and development in the extension of human lifespan and healthspan, while addressing the critical lack of early-stage funding in the biopharma industry, mirrors the foundational objectives encapsulated in the DSPF.

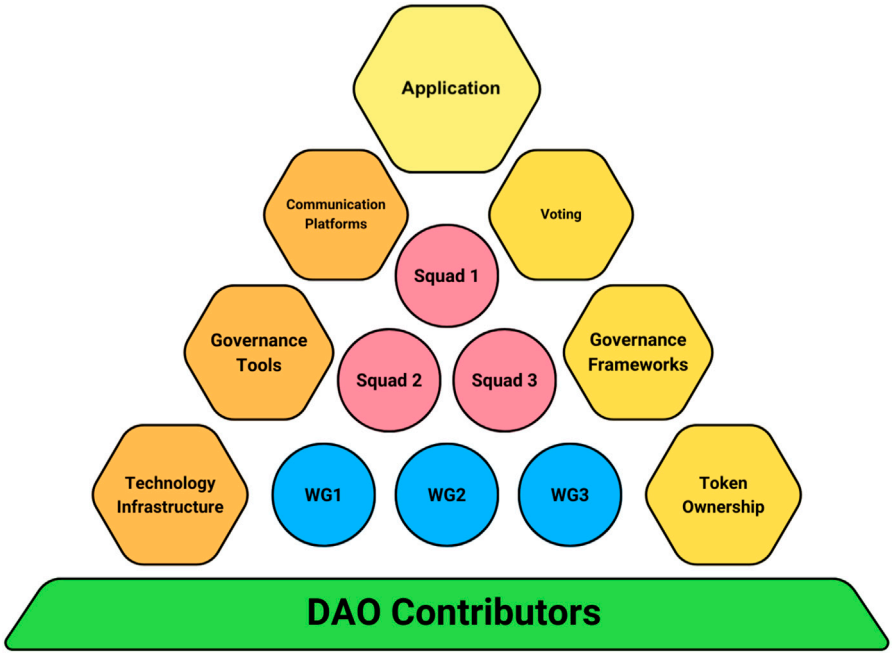

FIGURE 3
Specification of the components of the Decentralized Science Pyramid Framework (DSPF) based on practical examples. DAO contributors represent the 'Community' layer, exemplifying decentralized participation. The 'Organizational Structures' of the DSPF are represented by 'Working Groups' (WG), which are often further subdivided into smaller units, known as 'Squads'. The core layer 'Technology' is detailed through its key components: the 'Technology Infrastructure' (e.g., Distributed Ledger Technology), 'Governance Tools' (e.g., Snapshot), and 'Communication Platforms' (e.g., Discord). The third core layer of the DSPF, 'Governance,' is illustrated by 'Token Ownership,' which enables token-based 'Voting' and participation in decision-making processes under established 'Governance Frameworks' (e.g., a constitution). The 'Application' layer represents the tangible outcomes of these processes.

Each element of the DSPF (Community, Technology, Organizational Structures, Governance, and Application) is examined in the context of VitaDAO. Key differences between VitaDAO and other DeSci-DAOs, such as PsyDAO, CerebrumDAO, HairDAO, AthenaDAO, CryoDAO, and ValleyDAO, are highlighted selectively to exemplify the adaptability and applicability of the DSPF across various organizational models.

5.1 Operating core: community

In the DSPF, the community is not just a participant but the foundational layer, functioning as the Operating Core. The VitaDAO community is pivotal to every aspect of its operation, embodying the decentralized ethos of the DSPF. This community-driven approach ensures that the mission, governance, and ongoing success of VitaDAO are directly shaped by its members' collective actions and decisions.

Token-based voting rights empower members to shape the project's direction actively, ensuring that governance is both participatory and representative. Beyond governance, the community's influence extends into advocacy, outreach, and operational contributions, making it the engine driving the project's mission forward. Members engage through various platforms, such as forums (e.g., Discourse) and social media (e.g., X), to support VitaDAO's mission of fostering organic growth by onboarding new members and researchers. This dynamic interaction not only catalyzes knowledge dissemination, but also expands the project's impact, reinforcing the community's central role in achieving the objectives of VitaDAO. VitaDAO exemplifies the DSPF's emphasis on community-driven innovation by embedding member contributions deeply within its operational structure. Working groups, a critical manifestation of the community's will, are at the core of VitaDAO's activities. These groups focused on areas such as deal flow analysis, community awareness, and technical development, where the community's diverse skills and expertise were directly applied to advance the project's goals.

The election of Stewards to guide these working groups further illustrates a structured yet flexible approach to harnessing community talent. This model not only leverages a wide range of capabilities within the community but also reinforces a sense of ownership and agency among members. Their contributions are central to the ongoing success and development of VitaDAO, reflecting the DSPF's principle that the community (exemplified by contributors to the DAO), as the Operating Core, is integral to all aspects of decentralized scientific endeavors.

5.1.1 Contextual adaptations across DeSci-DAOs

The DSPF's emphasis on the community as the Operating Core demonstrates broad applicability across DeSci-DAOs. However, it is important to recognize that the concept of 'Community' can differ among DAOs. For instance, Cerebrum DAO identifies both

'Community members' and 'Token holders' as core stakeholders within its structure. Community members actively participate through platforms such as Discord, contributing to discussions and initiatives, but do not hold governance rights (Magierski et al., 2024). By contrast, token holders equipped with governance tokens (e.g., NEURON) are empowered to make decisions through formal mechanisms such as snapshot voting. However, both roles can be considered contributors to the DAO and, thus, part of the Operating Core, as defined by the DSPF, regardless of their specific governance privileges. This distinction in Cerebrum DAO's structure highlights the importance of recognizing different types of core stakeholders and tailoring engagement strategies to effectively address their distinct roles. Notably, token holders, while forming a subset of the broader community, act as a bridge between participation and governance, embodying the dynamic interplay central to the DSPF's conceptualization of the Operating Core.

5.2 Core layer: technology

VitaDAO exemplifies the DSPF's core layer element of Technology through its sophisticated use of blockchain technologies to create a transparent, secure, and decentralized operational framework. By leveraging smart contracts and IP-NFTs, VitaDAO established a robust infrastructure that underpins its governance and funding mechanisms. As discussed in Section 4.2.1, smart contracts automate critical processes such as proposal approvals and fund disbursements, ensuring transparency and efficiency.

In addition to blockchain technologies, VitaDAO employs various technological solutions to enhance communication, community engagement, and collective decision making. Platforms, such as Discord, are used for real-time communication and community building, allowing members to connect, share ideas, and collaborate seamlessly. Discord is also used to facilitate the (automated) onboarding of new members, moderation of servers and channels by bots, or collection of data for analysis (e.g., people joining or leaving the server, number of messages). The integration of tools such as Snapshot for off-chain voting and Discourse for detailed discussions enables VitaDAO to conduct inclusive and transparent decision-making processes. These platforms support the aggregation of community insights and preferences, ensuring that governance decisions reflect the collective will of members.

5.2.1 Contextual adaptations across DeSci-DAOs

The availability and increased accessibility of AI-based tools enable new levels of automation within DAOs and their communication platforms. For example, HairDAO utilizes automation to synthesize and summarize key discussion points from Discord, ensuring that members remain informed about critical developments and ongoing activities. PsyDAO employs an even more advanced approach through its PsyBEE project in which community-submitted links are autonomously processed into specialized datasets (PsyDAO, 2024a). These datasets, such as PsySciKG for peer-reviewed research, and the broader PsyDATASET for diverse psychedelic content, combine human collaboration with AI-driven automation to enhance scalability and efficiency (PsyDAO, 2024a). These examples illustrate how the DSPF's core layer of Technology accommodates innovative and adaptive tools that enhance both operational efficiency and community engagement. By integrating AI-driven automation with collaborative processes, DAOs such as PsyDAO align with the DSPF's emphasis on leveraging technology to support decentralized, scalable, and inclusive structures.

5.3 Core layer: organizational structures

VitaDAO's approach to organizational structures exemplifies the DSPF by showcasing a decentralized and flexible model that provides the necessary framework for effective coordination and communication across its community. Within the DSPF, Organizational Structures correlate with Mintzberg's Middle Line, facilitating the alignment of community-driven initiatives with the broader strategic objectives of the DAO.

In VitaDAO, these structures are designed to support the fluid collaboration of its members, enabling the community to self-organize into functional groups that address specific tasks or projects. This decentralized model ensures that strategic goals such as research initiatives or governance decisions are translated into actionable outcomes through well-defined processes. For instance, working groups within VitaDAO, which focus on areas such as deal flow analysis, community awareness, and technical development, are critical in operationalizing the DAO's vision (VitaDAO, 2024). These working groups act as the connective tissue within VitaDAO, ensuring seamless communication and coordination across the organization. Stewards elected to guide these groups play a pivotal role in maintaining alignment with VitaDAO's strategic goals, fostering accountability, and ensuring that the organizational structure remains adaptable to the needs of the community (White and Klaps, 2024). The organizational structures within VitaDAO are also integral to its interaction with the other core layers of the DSPF, particularly technology and governance. They provide a framework within which technology is utilized and governance is enacted, ensuring that the community's efforts are both effective and aligned with the DAO's decentralized ethos. These structures are key to the ongoing success and evolution of VitaDAO by enabling the community to self-organize and function efficiently.

5.3.1 Contextual adaptations across DeSci-DAOs

While the number and focus of working groups vary among DeSci-DAOs, there has been increasing emphasis on consumer products. For example, on 1 June 2024, Cerebrum DAO approved a governance proposal (CDP-5) to establish a Product Working Group, expanding beyond its initial structure of Coordination, Neuroscience Dealflow, and Awareness and Community working groups (Magierski et al., 2024; CerebrumDAO, 2024). This new Product Working Group was tasked with developing a strategy to create and deliver evidence-based brain-health solutions to consumers. The responsibilities of the working group span from user research and prototyping to full-scale product deployment and partnership management, illustrating how organizational structures can evolve to address market

opportunities and strategic goals. This adaptability demonstrates the applicability of DSPF in guiding DAOs as they expand their operational focus, balancing community-driven decision-making with structured execution frameworks.

5.4 Core layer: governance

In the DSPF, Governance serves as a central mechanism that empowers the community to self-regulate, coordinate, and maintain the decentralized ethos foundational to VitaDAO. Unlike traditional organizations, where governance is often a top-down process, VitaDAO's governance is aimed at being more decentralized, participatory, and transparent, aligning with the principles of the DSPF.

The governance structure within VitaDAO is facilitated primarily by the use of governance tokens (VITA). VitaDAO currently follows a meritocratic approach to governance with one VITA equal to one vote. Governance in VitaDAO is not limited to high-level decision-making but permeates every aspect of the organization. The election of Stewards, who guide the working groups, is a key element of this governance model. These Stewards are chosen by the community based on their contributions and expertise, ensuring that leadership within the organization is both meritocratic and responsive to the needs of the community. This process not only democratizes leadership but also fosters accountability, as Stewards are directly answerable to the members who elected them (White and Klaps, 2024).

Furthermore, the governance framework within VitaDAO includes mechanisms for continuous feedback and community inputs. Platforms such as Snapshot are used for off-chain voting on proposals, whereas forums and social media channels provide spaces for discussion and debate. These tools facilitate a transparent and inclusive governance process, ensuring that all voices within the community are heard and considered in decision making. VitaDAO's governance structure also plays a crucial role in aligning the organization's operations with its broader strategic goals. By enabling the community to participate directly in governance, VitaDAO ensures that its mission and activities are continuously shaped by those who are most invested in its success. This alignment is essential for maintaining the integrity of the project and ensuring that all operational decisions contribute to the DAO's long-term sustainability and impact.

5.4.1 Contextual adaptations across DeSci-DAOs

While many DeSci-DAOs follow similar token-based governance structures with only one token and meritocratic voting, PsyDAO offers a notable deviation through its dual-governance model (PsyDAO, 2024c). In PsyDAO, governance is distributed across two types of tokens, PSYC and PSY. PSYC tokens convey membership and operate on a one-person, one-vote system, granting PSYC holders comprehensive governance rights over the DAO's treasury and strategic decisions. By contrast, PSY tokens are fungible and grant proportional voting power, with their authority delegated by PSYC holders. This structure allows PsyDAO to balance individual representation through PSYC with collective financial governance through PSY (PsyDAO, 2024c). By accommodating such hybrid governance configurations, the DSPF Governance layer demonstrates its capacity to integrate both egalitarian and proportional decision-making mechanisms, ensuring that DAOs can effectively combine inclusivity with operational efficiency tailored to their objectives.

5.5 Apex: application

In Mintzberg's organizational model, the Strategic Apex is responsible for setting strategic direction and ensuring that the organization achieves its overarching goals. In the DSPF, this concept is reimagined as the Application layer, where VitaDAO's implementation of the DeSci principles extends beyond traditional funding mechanisms, embodying a holistic approach to accelerating longevity research. By embracing a decentralized governance model, VitaDAO not only allocates funds to promising research projects, but also engages in the active management and curation of intellectual property (IP) through innovative mechanisms such as IP-NFTs. This strategy enables VitaDAO to hold and manage IP rights and data assets, fostering an ecosystem in which scientific discoveries can be more freely accessed and utilized by the broader scientific community. VitaDAO's commitment to making research findings openly accessible is manifested in its support for projects that aim to be published in open-access journals and platforms. This approach ensures that the outcomes of funded research are available to all, contributing to a broader knowledge base, and encouraging further innovation in the field of longevity.

The Application layer in the DSPF represents the culmination of all layers, where the collective efforts of the community, supported by robust governance, advanced technology, and effective organizational structures, translate into tangible outcomes. By operationalizing these principles, VitaDAO exemplifies the DSPF's Apex, demonstrating how DeSci initiatives can have a tangible and positive impact on scientific research, funding, and dissemination, ultimately advancing the pursuit of human longevity.

5.5.1 Contextual adaptations across DeSci-DAOs

Given that many DeSci-DAOs, such as PsyDAO, AthenaDAO, and CerebrumDAO, have been modeled after VitaDAO, they share a common emphasis on aligning their application layer with their overarching visions. These DAOs focus not only on achieving their goals, such as accelerating longevity research or advancing psychedelic science, but also on creating tangible applications that generate sustainable revenue streams to fund further research and operations. A unifying strategy across these DAOs involves generating IP assets that can yield revenue and ensure the continuity of their missions. For instance, CerebrumDAO exemplifies how the application layer can manifest as something tangible through its recent efforts to establish a Product Working Group focused on consumer-facing brain health solutions (CerebrumDAO, 2024). This group is tasked with sourcing evidence-based products and services to create a sustainable funding model, while addressing the DAO vision of enhancing brain health. This highlights how the Application layer, as representative of the DSPF's Apex, not only acts as the culmination of all organizational layers, but

also translates into real-world outcomes that align with the DAO's goals.

6 Results

This study demonstrates that the DSPF effectively maps the dynamics of decentralized governance, collaboration, and innovation in DeSci organizations, confirming its utility as both a theoretical model and a practical tool. By adapting Mintzberg's organizational framework to decentralized contexts, the DSPF provides a nuanced understanding of the structural and operational complexities unique to DeSci. Mintzberg's emphasis on interconnectedness and coordination mechanisms, such as mutual adjustment and standardization, makes his framework particularly well suited for DeSci-DAOs, where governance relies on fluid interactions among community members, technology infrastructure, and decentralized decision-making structures. In contrast, models such as Systems Theory and Network Theory, while offering valuable perspectives on interrelations and network interactions, lack the structural details and practical mechanisms needed to analyze and optimize operational processes within decentralized scientific ecosystems (Napieralska and Kepczynski, 2024; Ballandies et al., 2024).

The DSPF extends its theoretical contribution by categorizing organizational components such as the operating core, technostructure, and governance structures, while emphasizing their dynamic interdependence. This provides a robust lens for analyzing decentralized systems and addressing specific challenges. Moreover, the 'Suggestions for Practical Application' embedded within the framework offer actionable insights tailored to improve the coordination, incentivization, and governance of DeSci-DAOs. For example, token-based governance mechanisms promote transparency and inclusivity, whereas decentralized project structures enhance adaptability and stakeholder engagement. These strategies demonstrate how the DSPF serves not only as a theoretical model but also as a practical guide for addressing real-world challenges.

The results confirm the hypothesis that the DSPF effectively captures the dynamics of decentralized governance, collaboration, and innovation in DeSci-DAOs. Evidence from the case study of VitaDAO illustrates how the DSPF maps these dynamics in practice, providing actionable strategies for improving both structural and operational effectiveness. Comparisons with other DAOs, such as PsyDAO and CerebrumDAO, further validated the framework's adaptability across diverse contexts, showing how it accommodates varying governance structures and operational models. By tailoring its practical suggestions to the specific challenges faced by DeSci-DAOs, the DSPF demonstrates its ability to bridge theoretical clarity with real-world applicability, supporting the development of decentralized scientific organizations.

Furthermore, the results underscore the capacity of the DSPF to address critical gaps in understanding and operationalizing decentralized governance. The framework equips researchers and practitioners with tools to analyze and optimize decentralized systems in diverse scientific settings, offering a foundational model for advancing the effectiveness of DeSci-DAOs.

7 Discussion

The DSPF delineates a comprehensive model for operationalizing DeSci, adapting Mintzberg's organizational structure to the distinct context of DeSci. Through the case study of VitaDAO, the DSPF has been practically exemplified, showing how DeSci can transcend traditional research paradigms by fostering a decentralized, community-driven approach to scientific innovation.

This framework emphasizes the critical role of integrating its core layers—Community, Technology, Organizational Structures, Governance, and Application—to achieve the strategic goals of the DeSci initiatives. The interconnectedness of these layers ensures that each component supports and enhances the others, leading to a cohesive and efficient framework. For instance, the community (Mintzberg's Operating Core) is empowered by decentralized governance mechanisms and supported by robust technological infrastructure, whereas organizational structures provide the necessary framework for coordination and communication. This integration not only facilitates the decentralized operation of DeSci projects, but also ensures their adaptability and responsiveness to emerging challenges and opportunities.

Despite its strengths, the DSPF faces inherent challenges that reflect the emerging nature of DeSci. These challenges include ensuring equitable participation across a diverse stakeholder base, managing the complexity of decentralized governance structures, and aligning the interests of a broad community with common goals. Addressing these challenges requires a continuous evolution of the framework, incorporating feedback from real-world applications, such as VitaDAO, and adapting to the rapid technological advancements that characterize the DeSci ecosystem.

It is important to acknowledge the limitations of this study. The adaptation of Mintzberg's organizational structures to DeSci was informed by both the researchers' active participation in various DeSci initiatives and an extensive review of the relevant literature. Although this combination of practical engagement and scholarly analysis provides a robust foundation, it also introduces potential biases associated with researchers' direct involvement in the field. For instance, researchers' experiences may have influenced the interpretation of data or the emphasis placed on certain aspects of the DSPF, leading to a potential overrepresentation of issues encountered in the specific contexts where they were most active.

Additionally, the authors' deep involvement in DeSci-DAOs while providing critical insights and practical grounding may also introduce limitations. This expertise may inadvertently narrow the focus of DSPF to align with the experiences and challenges observed in specific contexts. Consequently, certain aspects of DeSci-DAOs that differ from the authors' experiences may be underrepresented in the framework. A broader engagement with DeSci-DAOs and projects outside the researchers' direct involvement would further strengthen the generalizability of the DSPF.

Furthermore, while VitaDAO serves as the primary case study for the DSPF, its unique focus on longevity research and its specific governance and technological structures may not fully capture the diversity of potential DeSci applications. Although comparisons with other DeSci-DAOs, such as PsyDAO and CerebrumDAO, provide valuable insights into the adaptability of the DSPF, these comparisons remain limited in scope. The contextual differences among DAOs, including variations in goals, governance models, and operational

strategies, highlight the need for a more comprehensive analysis of a broader range of decentralized scientific initiatives. While the additional comparisons help demonstrate the DSPF's flexibility, they also underscore the framework's dependency on contextual alignment, raising questions about its scalability to vastly different domains. Ongoing research should critically assess whether the DSPF's assumptions hold across the full spectrum of DeSci-DAOs particularly in areas with fundamentally different objectives or less-structured governance models.

There is also the challenge of evolving technology and governance models within the DeSci ecosystem that may outpace the current framework. As technologies such as blockchain rapidly develop, the DSPF must be continuously updated to remain relevant. The applicability of the framework to new or emerging technologies and organizational models within DeSci has not been extensively tested, representing another area where future research is needed.

Future research should explore mechanisms to streamline governance processes, ensuring that they remain agile and effective while also being transparent and accountable. This includes developing protocols and tools that can facilitate consensus-building and conflict resolution, which are critical components for sustaining collaborative momentum in decentralized settings. Further validation across different scientific disciplines and organizational contexts is necessary to assess the adaptability and scalability of the DSPF. Additionally, operationalizing the DSPF to fully map out the best practices for DeSci-DAOs represents a critical next step. This operationalization would involve the development of practical guidelines, assessment metrics, and implementation frameworks tailored to the unique challenges and opportunities of decentralized scientific initiatives. By doing so, the DSPF can move beyond theoretical application, serving as a practical tool for improving coordination, governance, and community engagement within DeSci-DAOs. This ongoing development process will ensure that the DSPF evolves in step with the dynamic nature of DeSci and will continue to provide a foundational blueprint for decentralized scientific innovation.

8 Conclusion

The DSPF offers an innovative approach to operationalizing DeSci by integrating Mintzberg's Organizational Structures with the unique dynamics of DeSci. This framework provides valuable insights into the coordination, decision making, and innovation mechanisms essential for the growth of DeSci initiatives. The case study of VitaDAO demonstrates the practical applicability of the DSPF, showcasing how DeSci can revolutionize scientific research through decentralization, community engagement, and open collaboration. By adapting a well-established organizational model to a decentralized context, the DSPF contributes significantly to both organizational theory and the practical implementation of DeSci projects. As DeSci evolves, the DSPF needs to be continually refined to address new challenges and opportunities. Future research should focus on validating the framework across different contexts and on developing tools to facilitate its practical application. This ongoing evolution will ensure that the DSPF remains a foundational blueprint for advancing the frontiers of science through decentralized, community-driven efforts.

Data availability statement

Publicly available datasets were analyzed in this study. This data can be found here: Theory details within the submission.

Author contributions

LW: Conceptualization, Methodology, Visualization, Writing–original draft, Writing–review and editing. KG: Conceptualization, Investigation, Writing–original draft, Writing–review and editing. MM: Conceptualization, Validation, Visualization, Writing–original draft, Writing–review and editing.

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Conflict of interest

Author LW was employed by Molecule AG. Author MM was employed by Cerebrum DAO.

The remaining author declares that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Generative AI statement

The author(s) declare that no Generative AI was used in the creation of this manuscript.

Publisher's note

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