Decentralizing science: Towards an interoperable open peer review ecosystem using blockchain

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ABSTRACT

Scientific publication and its Peer Review system strongly rely on a few major industry players controlling most journals (e.g. Elsevier), databases (e.g. Scopus) and metrics (e.g. JCR Impact Factor), while keeping most articles behind paywalls. Critics to such system include concerns about fairness, quality, performance, cost, unpaid labor, transparency, and accuracy of the evaluation process. The Open Access movement has tried to provide free access to the published research articles, but most of the aforementioned issues remain. In such context, decentralized technologies such as blockchain offer an opportunity to experiment with new models for scientific production and dissemination relying on a decentralized infrastructure, aiming to tackle multiple of the current system shortcomings. This paper makes a proposal for an interoperable decentralized system for an open peer review ecosystem, relying on emerging distributed technologies such as blockchain and IPFS. Such system, named "Decentralized Science" (DecSci), aims to enable a decentralized reviewer reputation system, which relies on an Open Access by-design infrastructure, together with transparent governance processes. Two prototypes have been implemented: a proof-of-concept prototype to validate DecSci's technological feasibility, and a Minimum Viable Product (MVP) prototype co-designed with journal editors. In addition, three evaluations have been carried out: an exploratory survey to assess interest on the issues tackled; two sets of interviews to confirm both the main problems for editors and to validate the MVP prototype; and a cost analysis of the main operations, both execution cost and actual price. Additionally, the paper discusses the multiple interoperability challenges such proposal faces, including an architecture to tackle them. This work finishes with a review of some of the open challenges that this ambitious proposal may face.

1. Introduction

Blockchain has raised in recent years as a novel and promising technology that might have a great impact in classical information systems (Berdik, Otoum, Schmidt, Porter, & Jararweh, 2021) in well-established fields such as finance, health, media, commerce, supply chains, IoT, etc. Its decentralized architecture (Sai, Buckley, Fitzgerald, & Gear, 2021) allows new governance models

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based on different consensus mechanisms, encourages collaboration and promotes transparency, and, at the same time, imposes strict security features that makes incredibly difficult to create fraudulent records. However, this technology also raises new concerns (Casino, Dasaklis, & Patsakis, 2019) regarding suitability, scalability, interoperability, security and data privacy issues.

Nevertheless, the potential of blockchain does not only promise to change industry but also other fields like academia. For example, blockchain can be used to mitigate the existing security issues concerning the sharing of students' credentials (Mishra, Kalla, Braeken, & Liyanage, 2021) or to check code copyright and combat plagiarism (Jing, Liu, & Sugumaran, 2021). In this paper we introduce "Decentralized Science" (DecSci), a decentralized and interoperable system that relies on emerging distributed technologies such as blockchain and IPFS, to mitigate problems identified in the processes of peer review and publication of scientific articles.

1.1. Innovations in the scientific process

In the last decades, the Internet has revolutionized multiple fields. However, the production of science and its peer review process have not seen large changes with respect to the traditional paper-based publication and review practices (Spier, 2002). The communication of knowledge still relies on academic articles, that journals collect and publish with certain periodicity for the consumption of scholars in academic institutions. The criticisms to nowadays scientific publication and peer review processes include concerns with respect to quality (Goldbeck-Wood, 1999), fairness (Wenneras & Wold, 2001), cost (Bergstrom & Bergstrom, 2004), performance (Huisman & Smits, 2017), and evaluation metrics accuracy (E., 2006).

Still, the advent of the Internet brought some changes to the scientific process. Its reduction of distribution costs allowed for broader access to scientific knowledge, and thus further questioning of the role of traditional publishers which previously assumed the distribution effort (Whitworth & Friedman, 2009a). Thus, alternatives emerged, especially with respect to scientific dissemination, grouped around the "Open Access" movement (Eysenbach, 2006). The Open Access (OA) movement, leveraging the replicability of digital content, aims to provide free access to the published research articles. And even though it is far from universal, it is generally recognized that the Open Access movement has reduced the economic cost for readers to access knowledge (Evans & Reimer, 2009).

However, despite its partial success, Open Access potential to democratize access to knowledge has been questioned (Knöchelmann, 2020). In fact, OA has not successfully challenged traditional publishers' business models (Larivière, Haustein, & Mongeon, 2015) which are often charging both readers and authors (Van Noorden et al., 2013).

With respect to the traditional peer review system, despite the multiple criticisms received mentioned above, only few alternatives have gathered success (Walker & Rocha da Silva, 2015; Ware, 2008). The literature provides multiple proposals around "open" peer review (Ford, 2013), which would enable transparent and public reviews, versus the traditional blind and private reviews (Lee, Sugimoto, Zhang, & Cronin, 2013). In fact, relying on such open peer review models, we can find some proposals of reputation networks for reviewers (Song, Hu, & Gehringer, 2015), which may provide new quality control processes for the reviewers, authors and editors. It is worth noting that the start-up Publons,[1] provides a platform to acknowledge reviews and open them up. The project reached quickly a large reviewer community, and it was recently absorbed by Clarivate Analytics publishing conglomerate.

In the last decades, other initiatives that challenge the traditional science publication process have emerged. *Preprints* are versions of scientific articles which have undertaken formal peer review, and have not been published formally in a journal or conference proceedings. Today, there are multiple widely successful platforms to host preprints and provide them visibility, like arXiv[2] or Preprints.org[3] (Shuai, Pepe, & Bollen, 2012).

Besides, social networks crafted for the scientific community have also found their niche. These enable scientists to upload their authored published articles, sharing them with fellow scientists whom they can connect. Example successful platforms include Academia[4] or Research Gate.[5]

These platforms are all centralized, that is, relying on a single platform owner which controls the infrastructure. Such centralization has multiple consequences (Benkler, 2016; Berners-Lee, 2010; Chaudhry et al., 2015) such as: problems related to monopolistic business models which affect users and their data; the need to depend on and trust a third-party which may change its policies anytime (e.g. in case of a change of business model, or a buy-in); market dominance over derived services such as metrics (e.g. JCR Impact Factor) or databases (e.g. Scopus); paywalls and the derived need of subscription packages for research institutions; and overall, issues related with the lesser control of the researcher community over their data and processes.

1.2. Decentralized alternatives

Decentralized alternatives aim to tackle issues from a different standpoint, aiming to avoid the traditional issues with centralized systems. In particular, the new generation of decentralized technologies that have emerged in recent years, such as blockchain and IPFS (see Section 2), have enabled a broad spectrum of emergent projects tackling multiple fields, including Finance, Internet of Things, supply chains, education, or governance (Hassan et al., 2020). These projects aim to take benefit from blockchain

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[1] https://publons.com/
[2] https://arxiv.org/
[3] https://www.preprints.org/
[4] https://www.academia.edu/
[5] http://researchgate.com/

affordances (Rozas, Tenorio-Fornés, Díaz-Molina, & Hassan, 2021), such as its transparency, tokenization, codification of trust, or decentralized infrastructure. And in particular, there is an emergent diversity of projects aiming to tackle issues concerning scientific publication and peer review (Bartling, 2019; Leible, Schlager, Schubotz, & Gipp, 2019).

The literature covers multiple applications of blockchain (and related technologies) for improving the Open Science process. The most straight forward applications concern the use of time-stamping using blockchain, to assert authorship and provenance relying on the transparency and immutability of the ledger (Gipp, Breitinger, Meuschke, & Beel, 2017; Sivagnanam, Nandigam, & Lin, 2019). However, the most common application is the use of blockchain capabilities of managing crypto-tokens, i.e. transferable electronic representations of value, such as crypto-currencies or embedded permissions. Thus, there are multiple proposals to reward activities using tokens, such as incentive collaboration (Duh et al., 2019), management of data access permissions (Mamoshina et al., 2018), reproducibility of studies (Kochalko, Morris, & Rollins, 2018), endorsement of publications (b8d5ad9d974a44e7e2882f986467f4d3, 2016), peer reviewing (Kosmarski & Gordiychuk, 2020; Spearpoint, 2017), or as novel methods of funding research (Lehner, Hunzeker, & Ziegler, 2017).

Other works rely on the capabilities of blockchain to facilitate transparency and openness, e.g. enhancing the Open Access process (Tenorio-Fornés, Jacynycz, Llop-Vila, Sánchez-Ruiz, & Hassan, 2019) or Open Science integrity (Bell, LaToza, Baldmitsi, & Stavrou, 2017). Finally, other works rely on *smart contracts*, i.e. software that is automatically executed in a decentralized blockchain network, e.g. to provide automatic processes for scientific publication (Dhillon, 2016; Duh et al., 2019), or reproducibility of studies and experiments (Dhillon, 2020).

1.3. A proposal for open peer review

This paper proposes the development of a decentralized publication and peer review system relying on an Open Access and open review model. It focuses on improving the peer review system, relying on an open review model, and on rewards for reviewers. However, it does not rely on a crypto-currency like many of the reviewed works, but on a reputation system to evaluate both reviews and reviewers. The proposal benefits from multiple of the mentioned blockchain characteristics, including transparency, new reward models, smart contract automatization, time-stamping, and decentralization.

Thus, this work joins other mentioned initiatives in challenging the current infrastructure that supports what it is considered an oligopoly of traditional publishers (Larivière et al., 2015). As mentioned above, the Open Access movement has enabled a portion of academic publications to remain freely available. However, these publications are still mostly served from infrastructure controlled by a few industry players (Elsevier, Springer, Clarivate). Thus, infrastructure ownership enables them to exert control, impose policies (e.g. limitations to dissemination, copyright transfer, Open Access fees price, embargo periods) and concentrate profits (Fuster Morell, 2010).

The system proposed in this work, named "Decentralized Science" aims to enable the scientific community to hold higher control over their infrastructure. Thus, the proposal involves the decentralization of 3 main parts of the scientific process:

- The process of selecting reviewers and recognizing their work, through the use of a reviewer reputation system in which review reports may be rated.
- The (server-less) research dissemination, by distributing academic articles through the IPFS peer-to-peer network, and by default provisioning an Open Access by-design infrastructure.
- The transparency of the whole peer review process, through the use of blockchain technologies. Thus, review reports will be public following the open peer review model (Ford, 2013), together with the communication flow from paper submission to reviewer proposals and review submissions.

Concerning specifically with the peer review process, the proposed system tackles four issues: the overall quality of the reviews; the fairness of the process for the authors; the fairness of recognition (and payment) for reviewers; and the challenges associated with the search and selection of good reviewers for the journal editors.

To achieve such an ambitious goal and taking into account that our proposal uses distributed technologies that are not mature yet, we have decided to use an iterative and incremental approach building partial prototypes that allow us to validate their viability. These prototypes are the result of various interviews with other interested parties, that have subsequently participated in their validation. Furthermore, for our proposal to be successful, it must be able to inter-operate with other existing platforms (centralized or decentralized), which represents significant challenges. This paper extends our previous work (Tenorio-Fornés et al., 2019) in several ways: (1) it delves into the fundamental requirements that give value to our proposal, (2) it extends the system architecture and describes a first prototype search tool to find reviewers that has been co-designed and validated with journal editors, and (3) it analyzes the interoperability challenges faced by our platform to integrate and collaborate with other existing platforms and technologies.

The rest of the paper is organized as follows. First, Section 2 reviews the main decentralized technologies used, together with related concepts. Section 3 describes the main requirements for the system, which is later designed in Section 4. Following, Section 5 describes two software prototypes: (1) a proof of concept to assess the technological feasibility of the proposal (Section 5.1) and (2) a minimum viable product for the management of peer reviewing (Section 5.2). Section 6 presents the evaluation of the system, consisting of three studies: a survey to evaluate the perception of the problems and proposed solutions (Section 6.1), a series of interviews to evaluate the relevance of the problem and adequacy of the prototype to solve them (Section 6.2), and a cost analysis with regards to execution cost and price of the major operations, including a related scalability analysis (Section 6.3). Additionally, Section 7 discusses the challenges to integrate decentralized applications with existing technologies and online communities. To conclude, Section 8 tackles the main challenges and open questions that this proposal entails.

2. The decentralized technologies used

The use of decentralized technologies is an essential part of our proposal to provide transparency and accountability throughout the scientific paper publication process (submission, revision, publication and access) and, at the same time, avoid the concentration of power in a few actors. Using these technologies to implement the core of the platform we ensure that every fundamental transaction in the system will be publicly recorded and validated by a majority of the network participants according to a pre-established set of rules. This way, none of the participants has more decision power than the others because the transactions in the platform are accepted or rejected using a majority consensus mechanism. Furthermore, the public and permanent log of these transactions promotes transparency and trust in the process. Next, we introduce the main distributed technologies on which our proposal is based.

IPFS (Benet, 2014) is a peer-to-peer hypermedia protocol that enables the distribution of files using a decentralized network. Files are divided in blocks that are indexed using cryptographic hashes. These blocks are then distributed (and possibly replicated) among the network nodes. When a file needs to be retrieved, its blocks can be downloaded simultaneously from different peers. Note that new participants can add new nodes to the network and replicate the content they are interested in. We propose the use of IPFS to store and share the different versions of the papers, from first drafts to final versions, and peer review reports.

Blockchain is the underlying technology that supports Bitcoin (Nakamoto, 2008), the first fully distributed digital currency. Monetary transactions are collected in blocks that are accepted or rejected by the peer-to-peer network using a consensus mechanism in which at least half of the network needs to agree. Each new block is then linked to the previous one creating an immutable chain of blocks (blockchain) or public ledger that contains all the historical transactions performed. It is interesting to mention that each node of the network stores a full copy of the blockchain so that it can autonomously accept or reject future transactions. The order in which transactions are recorded in the public ledger is decided by the node (miner) that produces the next valid block. In order to produce new blocks, the nodes compete against each other to solve a computationally expensive problem. This computational effort is rewarded by the protocol with incentives (new bitcoins) to maintain the security of the ledger.

Ethereum (Buterin, 2014) extends the blockchain technology to enable to execution of small programs or *smart contracts* creating the first blockchain-based distributed computing platform. These smart contracts are stored in the blockchain (so they are immutable) and triggered using transactions that define which part of the program must be executed. Its functioning is similar to the Bitcoin blockchain in which all the nodes validate the bitcoin transactions. In the Ethereum network, all the nodes execute the same smart contracts to reach a majority consensus, regarding the changes they produce in the public ledger that defines the state of the network. Each smart contract, therefore, defines a set of rules based on its code and once they are deployed they can be executed autonomously (De Filippi & Hassan, 2016). In summary, smart contracts are relevant because they allow the transparent execution of immutable programs in a trustless network. Some examples of Ethereum-based decentralized applications are prediction markets (Jacynycz, Calvo, Hassan, & Sánchez-Ruiz, 2016; Peterson & Krug, 2015) or social networks (Larimer et al., 2016). We propose the use of smart contracts to enforce transparency through the peer review process, and to implement a reviewer reputation system.

3. The proposal requirements

The proposed system, named "Decentralized Science" (abbreviated DecSci), aims to provide a decentralized platform for the scientific process, from submission to publication, with a special attention to the peer review process. It relies on three pillars, which are covered in this section: a decentralized reviewer reputation system, an Open Access by-design infrastructure, and a transparent governance.

3.1. A distributed reviewer reputation system

Typically, a major issue for editors and journals is accumulating the knowledge on the reliability and quality of reviewers. This valuable data is often kept private to publishers and their journals, reinforcing their influential positions. In fact, it is hard to predict the quality of a potential reviewer, even with knowledge on their training and past experience (Callaham & Tercier, 2007).

DecSci incorporates a new element to the traditional peer review communication work-flow: the option to rate the reviews, and then building metrics around those ratings, providing a reviewer reputation system (Resnick, Kuwabara, Zeckhauser, & Friedman, 2000). Thus, this opens the possibility for reviewers to be rewarded or penalized depending on the quality, fairness or speed of their reviews.

Building an open and public reputation system has multiple benefits for reviewers, including recognition and visibility (Rajpert-De Meyts, Losito, & Carrell, 2016), but also monetary incentives e.g. through cryptocurrencies (Jan et al., 2018). Besides, such open system is expected to reduce biased and unfair reviews, due to public exposure (Wenneras & Wold, 2001; Whitworth & Friedman, 2009b).

3.2. Open access by-design

Open Access refers to the principles and practices in which research outputs are distributed online, free of cost or other access barriers.[6] Thus, through the growth of Open Access, publishers provide research articles freely to readers. However, as mentioned above, since publishers are also the owners of the dissemination infrastructure, they are capable to establish certain rules and restrictions. For instance, they may charge authors unreasonable fees to opt for the Open Access option (Solomon & Björk, 2012), or demand restrictions or year-long embargoes for disseminating the final version (Björk, Laakso, Welling, & Paetau, 2014).

The DecSci proposal involves a decentralized infrastructure also to store and host all the documents involved in the scientific process. Thus, the different versions of the research paper, together with its reviews, are deployed publicly through the IPFS peer-to-peer network (Benet, 2014) (see Section 2). In such network, it is significantly hard to restrict access to the provided documents. Therefore, the proposed system implicitly enables unrestricted Open Access, facilitated by its decentralized infrastructure. This is designed in order to avoid dominant market positions such as those mentioned by current publishers. In fact, in case DecSci stopped working, the uploaded documents would still remain available in the IPFS distributed network, and links to them would still work as usual.

3.3. Transparent governance

As mentioned above, among the multiple issues of the current scientific process, there is a lack of transparency. That is, processes are typically private and closed, controlled by publishers, and depending on their infrastructure. Similarly, communications across authors, reviewers and editors remain private, and may enable arbitrary or biased results. Whitworth and Friedman (2009b).

DecSci aims to surpass these limitations through significantly increasing the transparency of the processes involved, hoping to improve speed and fairness in parallel. Thus, it proposes to record in a public blockchain, i.e. a distributed ledger, the interactions concerning article submission/publication, reviewer assignment or review submission. Therefore, previously obscure processes such as the reviewer selection or the review reports, would be open publicly. In addition, blockchain time-stamps every interaction and provides a theoretically tamper-proof mechanism, and thus the processes can be monitored by third-parties, audited, and eventually held accountable.

More research would be needed concerning the effects of both open reviews and open communication process, since it may influence the dynamics and incentives for journals and not just for authors or reviewers. Nowadays, journals are penalized for accepting irrelevant papers (i.e. which will not be cited, or have low quality), but are not penalized for rejecting valuable papers (Garfield, 2007; Whitworth & Friedman, 2009a). Thus, high rejection rates are typically encouraged. Within DecSci though, the latter would be also penalized, potentially triggering different dynamics for quality control and filtering.

Overall, we believe the transparent governance processes, combined with the decentralized infrastructure, enables experimentation and the emergence of novel work-flows (Whitworth & Friedman, 2009b).

4. System design using a decentralized architecture

The DecSci platform aims to support the whole peer review process, from paper submission to acceptance or rejection, as well as the rating of peer reviews to build a reviewer reputation network. Our platform relies on the two decentralized technologies introduced in Section 2: IPFS and Ethereum Smart Contracts, leveraging on recommendations from literature combining both (Chen, Li, Li, & Zhang, 2017; Nizamuddin, Hasan, & Salah, 2018; Tenorio-Fornés, Hassan, & Pavón, 2018). Both are peer-to-peer networks that provide the foundations of our proposed system.

On the one hand, *IPFS* provides a distributed file system to store and share documents such as the different versions of the paper, from first drafts to final versions, as well as the peer reviews generated during the revision process. On the other hand, *Ethereum Smart Contracts* are used to implement the rules of the system with transparency, such as only accepting reviews from invited reviewers, and register all the interactions in the blockchain. Note that the interactions are automatically time-stamped depending on the block in which they are accepted and cannot be tampered or deleted afterwards, creating a reliable log of the peer review process.

Each article and review stored in the IPFS network has a unique identifier (its address) which is stored in the blockchain, facilitating integration and direct access. The IPFS nodes storing the information may be provided by those actors deploying the system (such as publishers) or by third-party services such as Pinata.[7] Thus, this architecture provides free access and persistence to the registered information, and ensures its independence from centralized servers.

It is important to remark that, although DecSci relies on these novel technologies, users are not required to have any technical knowledge about them. Users interact with the platform using a web application that handles all this technical details for them, and users only need to have a valid identity in the network (an Ethereum address). For example, the sequence diagram shown in Fig. 1 describes the main interactions during a peer review process and below we describe the basic ideas to implement them.

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[6] We do not refer here to the Open Access strict definition in which it is required that the article is not only freely accessible, but also open-licensed, removing further barriers to copying or reuse (e.g. as in PLoS journals).
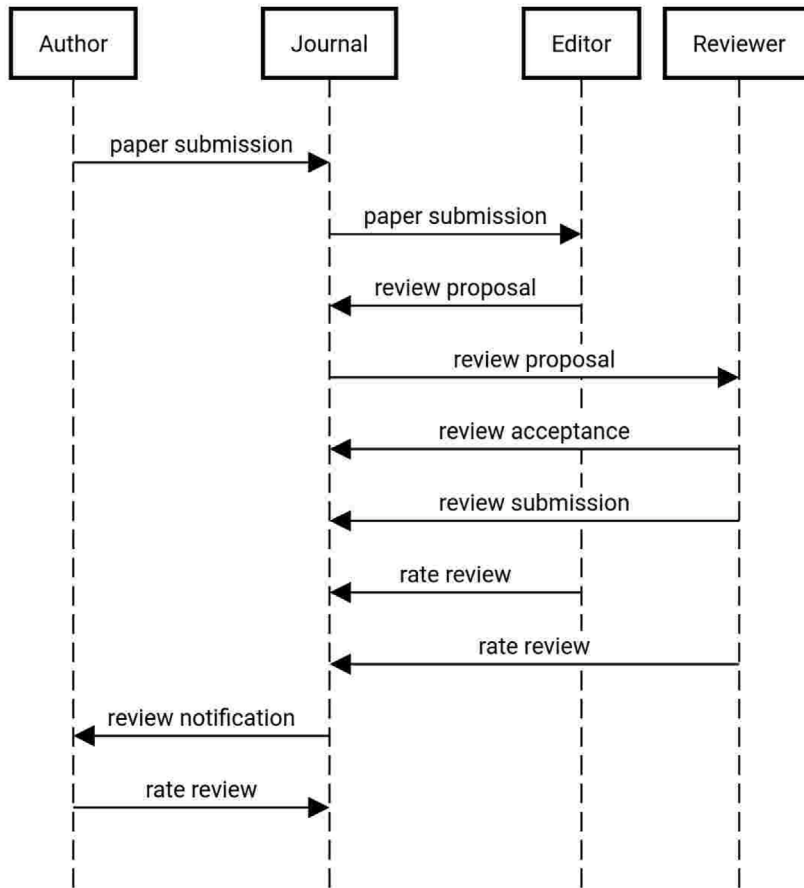
[7] https://pinata.cloud

Fig. 1. Sequence diagram of a peer review process.

Paper submission When an author submits a new paper to the platform, the paper is automatically uploaded to the IPFS network so the IPFS address can be used as an unique identifier of the document. Next, the platform creates an Ethereum *smart contract* that will manage and record the peer review process for that specific paper. Note that the Ethereum transaction that creates the smart contact can be used to verify that the authors submitted the paper at some specific time. This smart contract will record the Ethereum addresses of the authors and journal editors.

Review proposal Journal editors may invite reviewers to review a specific paper, adding this *review request* to the paper's *smart contract*. This interaction records the reviewer's Ethereum address as well as an optional submission deadline for the review. The reviewer may respond accepting or rejecting the review request, in which case the editor can invite another reviewer.

Review submission When a reviewer submits a review, the document is automatically uploaded to the IPFS network. Then, the reviewer carries out an Ethereum transaction to the smart contract using the IPFS address of the review as well as her verdict (acceptance of rejection of the paper). In the event of a missing review or delay, a penalty can be applied to the reviewer's reputation in the reputation system.

Review rating Our proposal introduces a reputation system for reviews (Section 3.1). The actors involved in a peer reviewing process, i.e. the authors, editors and other reviewers, can rate the submitted review reports. These ratings are recorded in the blockchain.

   One of the most important aspects to guarantee that the review process works correctly is to have a good base of reviewers who are willing to collaborate and whose knowledge and interests covers the different topics of the journal. In order to create better matches between reviewers and submission and, therefore, increase the quality of the revision process, DecSci incorporates a reputation system for reviewers and provides a search tool for the editors. This search tool can be use to find good candidates according to their interests, previous reviews and reputation rates. Below we describe this interactions in the platform, Fig. 2 provides a sequence diagram of these interactions.
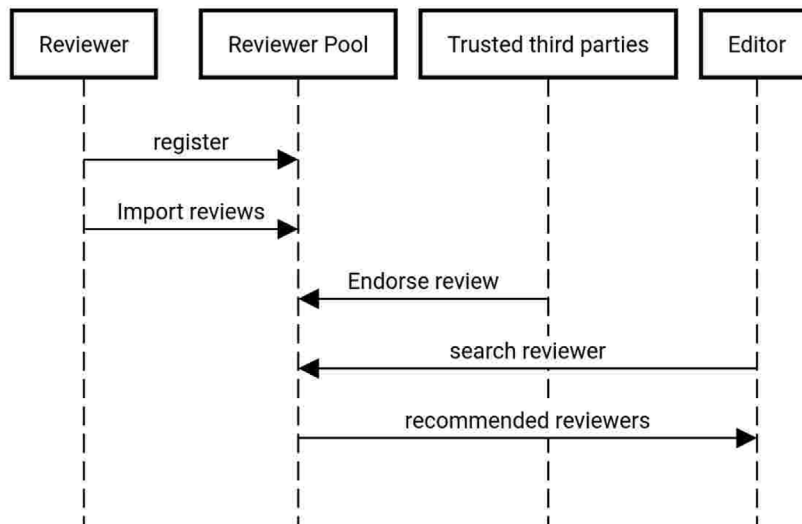
Fig. 2. Sequence diagram of reviewer registration, endorsement and search.

Register as reviewer Interested reviewers only need an Ethereum address to register in the system. Their interests and areas of expertise are also stored in the blockchain and can be updated at any time.

Import review Reviewers can import their previous reviews to the system. Several reviewers already have profiles and reviews stored in other online communities such as Publons, post-publication peer review services such as F1000Research or Peerage of Science and Academic databases such as ORCID or Crossref. As explored in Section 7.3, integrations with such systems are being developed.

Endorse review As anybody can freely import their previous peer reviews, there is a need for applications to decide if these reviews can be trusted or not. The system enables a way for other actors to endorse the validity of the imported reviews. Section 7.4 offers a detailed discussion on how this system would be implemented.

Search reviewer Journal editors should be able to find the most relevant and better reviewers for each paper. In Section 5 we describe our work to provide a useful and intuitive web interface to facilitate this task and find reviewers with relevant research interests, showing relevant information about them such as their reputation, acceptance rate, timelines and previous reviews.

5. Implementation

In order to realize our system proposal, we have developed two distinct prototypes:

- First, a proof-of-concept prototype to validate the technological feasibility of the proposal. Such implementation enabled the performance of preliminary tests of each of the platform's interactions, and to validate the feasibility of our decentralized architecture for the implementation of the system. Thus, this prototype provides a simple version of the requirements specified in Section 3, and the interaction design from Section 4.
- Second, a Minimum Viable Product prototype for Reviewer Management, co-designed with journal editors. This functional software is focused on the most relevant functionalities that current journals require, and facilitate its integration with existing journal infrastructure. Thus, it focuses on a subset of Section 4 interactions, in particular those relevant for reviewer search and reviewer data (in order to extract quality metrics).

5.1. A proof-of-concept to validate technical feasibility

As explained above, this proof-of-concept prototype allows us to test the main interactions using the aforementioned decentralized technologies, namely Ethereum, Smart Contracts and IPFS. This software implements a basic version of Section 3 requirements and Section 4 design. The software is publicly available as free/open source, publicly available in Github.[8]
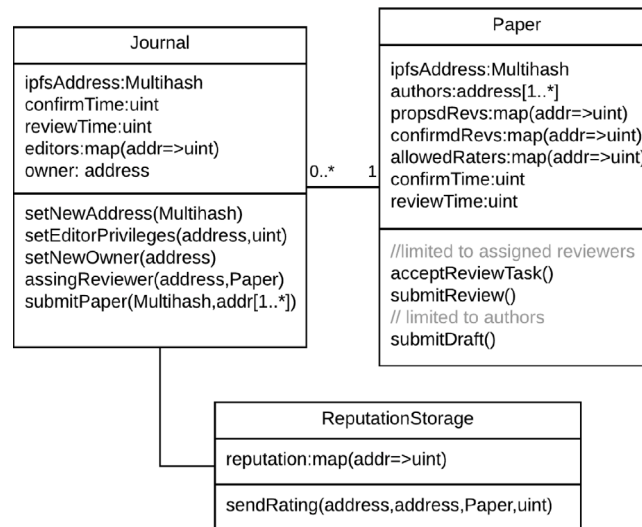
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[8] https://github.com/DecentralizedScience/Gateway

Fig. 3. Proof-of-concept UML architecture diagram.

Thus, this prototype architecture uses IPFS as a distributed file system to store and share the review reports and papers, and the Ethereum Blockchain to implement the logic of the system and to manage its state. The prototype uses a web interface that communicates with IPFS and Ethereum networks using JavaScript libraries. It proposes the use of Metamask[9] to provide user-friendly management of Ethereum identities.

This proof-of-concept prototype uses three different Ethereum smart contacts to run the platform's inner functioning, as shown in Fig. 3. The *Journal* smart contract provides functionality for the submission of papers, the selection of editors, and the management of review requests. The *Paper* smart contract serves to provide a digital id for the papers, manages the submission of review reports, and specifies who is allowed to rate a review report. Finally, the *ReputationStorage* smart contract manages the ratings of the peer reviews, updating the rating of reviewers upon receiving new ratings, if these ratings are allowed by their Paper contract.

The data structures of these Smart Contracts are optimized for Ethereum performance using data types such as maps instead of arrays and Ethereum addresses. Thus, (1) the Journal smart contract maintains a map of journal editors addresses; (2) each paper stores a map of proposed and accepted reviewers, as well as who is allowed to rate the reviews; and (3) the reputation contract stores a mapping of the reputation of each reviewer. The relationships between papers and journals that are not crucial to store in the blockchain are shared in events, thus reducing the cost of these operations. The events used in this smart contract are the following[10]: PaperCreated, ReviewerProposed, ReviewerConfirmed, ReviewReceived, NewDraft, JournalAdress, NewOwner, PrivilegeChange, PaperSubmitted, RatingReceived.

Note that, for each rating, the system registers the rater and modifies the reviewer's reputation, performing an exponential smoothing[11] of the score received (Gardner Jr, 2006). In this case, exponential smoothing is used to calculate the average of the score without knowing the total number of raters.

This prototype does not cover advanced reviewer interactions (register, import, search and endorse) which is the focus of the second prototype, explained in the following subsection.

5.2. A minimum viable product for reviewer management

This functional prototype was designed with participatory methodologies (Lean Design and User-Centered Design), in close collaboration with journal editors (Tirador & Tenorio-Fornés, 2019). Thus, it is designed to respond to their needs. The principal value proposition (Osterwalder, Pigneur, Bernarda, & Smith, 2014) for these journal editors is (1) a tool to find reviewers that (2) provides relevant metrics about them such as their timeliness or acceptance ratio, and (3) access to the open peer reviews of these reviewers. Fig. 4 shows a detail of the Graphic User Interface (GUI). The interface allows journal editors to find relevant reviewers in the system. As further explained in Section 7.1, the prototype is integrated with the well-known publication management software Open Journal System (OJS), enabling journal editors to see the journal's reviewers, and request a review using their peer review management system. The GUI offers additional functionalities for the selection of peer reviewers currently unavailable at

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[9] https://metamask.io

[10] The events are not described in detail for the sake of brevity, although most are self-explanatory. They can be seen in detail in the Solidity smart contract https://github.com/DecentralizedScience/Gateway/blob/master/contract/decentralizedScienceContract.sol

[11] The alpha value used in the exponential smoothing is 0.2.
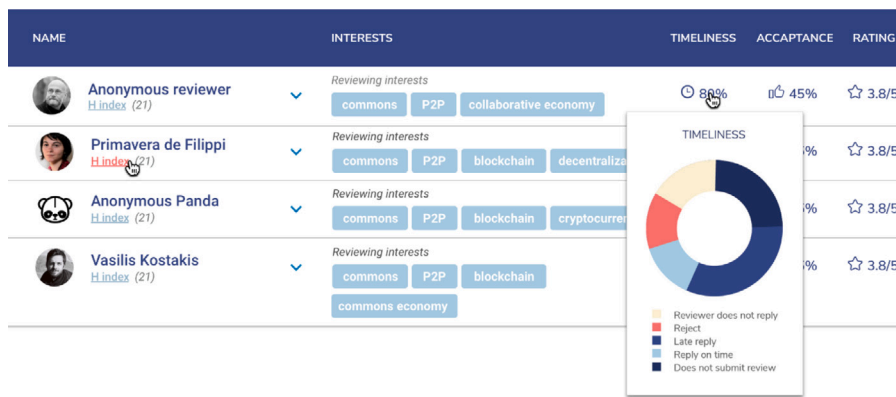
Fig. 4. Decentralized Science Reviewer search GUI.

OJS GUI (Tenorio-Fornés & Pérez Tirador, 2020). Concretely, it provides information about reviewers such as the acceptance ratio, the reputation, or the timelines, and facilitates access to their previous review reports.

However, this prototype does not just rely on centralized legacy software, but combines both centralized and decentralized technologies. In particular, (1) it uses Ethereum smart contracts to provide a decentralized management of the logic and state of the system, and (2) uses IPFS to store in a decentralized network larger files such as academic papers or the content of peer review reports. This way, using decentralized technologies we aim to promote the transparency of the peer reviewing process (Section 3.3) and provide an open access by design infrastructure (Section 3.2) for such information. Furthermore, maximizing interoperability and decentralization, we enable the participation of other third parties and prevent the enclosure of the information in data silos or walled gardens (Berners-Lee, 2010).

The implemented application interacts with these decentralized technologies to store, update and retrieve the needed information about the peer reviews managed by the system. Currently, the interaction with these decentralized technologies is done via a NodeJS implementation of the public GraphQL API (explained in Section 7.2). Such implementation accesses both the existing centralized and private information of journals, and the publicly shared and decentralized information Decentralized Science promotes. Thus, the software provides a web search interface that access both centralized and decentralized data, abstracting the technological differences for a better user experience.

6. Evaluation

We have performed three different and complementary evaluations. The first one consists on a survey to collect quantitative information regarding the response of potentially interested users with different profiles in a platform like DecSci. That is, an exploratory study to assess whether our proposal would attract enough early adopters to enable further exploration and validation.

The second evaluation consists on a set of interviews to validate both the problem and the solution. Thus, we performed interviews to better understand the problems faced by the editors during the peer review process, and we interviewed reviewers to validate our search tool for its relevant audience.

The third evaluation consists on a cost analysis, both in execution cost and price cost (in dollars), to assess the scalability of the proposed system, especially when relying on the Ethereum network.

In the first two evaluations, which rely on social research, our methods followed the guidelines and ethical considerations of the International Sociological Association.[12] Thus, we required standard written informed consent of the volunteer participants, which allowed the use of the data gathered. To ensure the right to privacy, individuals were anonymized in field notes.

6.1. Exploratory study to assess the interest in DecSci

6.1.1. Goals

The main goal of this exploratory study is to evaluate whether a platform like DecSci sparks enough interest among researchers and editors. In particular, we will assess (1) if there is a shared feeling about the need to improve the current article review process, (2) whether the different actors involved think that a reputation system could help, and (3) possible resistances regarding the use of such a reputation system.

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[12] https://www.isa-sociology.org/en/about-isa/code-of-ethics

Table 1

Exploratory study survey to assess the interest in DecSci.

1. As an author, I think that the quality of the review process can be sensibly improved.
2. As an author, I think that the fairness of the review process can be sensibly improved.
3. As a reviewer, the recognition, reputation or rewards I receive feels fair in relation to the amount of work that I do.
4. As an editor, I have difficulties finding good reviewers (quality, relevance, timeliness).
5. As an author, I would prefer to submit my work to a journal in which reviews can be publicly rated (on a reviewer reputation system).
6. As a reviewer, I would prefer to submit a review to a journal in which my review would be publicly rated (on a reviewer reputation system).
7. As a reviewer, I would only submit a review to a journal which rates its reviews, if I remain anonymous.
8. As an author/editor/reviewer, I would like to be able to rate the reviews of the papers I am working with.
9. As an editor, I would find a reviewer system sensibly useful to find relevant, timely and/or high quality reviewers.
10. I believe that a reviewer reputation system could sensibly improve the quality and/or fairness of the peer review process.
11. I believe that a reviewer reputation system could sensibly improve the recognition, reputation or rewards I receive for my reviews.

Table 2

Exploratory study survey results using a Likert scale from 1 (strongly disagree) to 5 (strongly agree).

Statement	#Answers	Mean	Mode
(1) Quality	35	4.2	4
(2) Fairness	36	4.4	5
(3) Recognition	34	2.4	2
(4) Finding reviewers	30	3.9	3-4
(5) Author resistance	36	3.9	4
(6) Reviewer resistance	34	3.6	4
(7) Anon. reviewer resistance	34	3.1	3
(8) Want to rate	36	4.3	5
(9) Improve reviewers search	30	3.9	4
(10) Improve quality/fairness	36	4.1	4
(11) Improve recognition	35	3.9	4

6.1.2. Target population

Representatives of the 3 main actors involved in the review process, namely authors, reviewers, and editors. Given the exploratory nature of this study, we only intent to target a small group of researchers and the conclusions will not necessarily represent the opinion of the whole academic community. Additionally, most researchers have experience at least in 2 roles, as authors and reviewers.

We collected answers to our survey from 3 different academic groups: an "Open Science Ecosystem" Telegram group with more than 150 participants from different projects involved in the development of decentralized and open-source software solutions for open science; our faculty department that comprises more than 40 full time researchers and professors of Computer Science; and 36 subscribers to the DecSci's newsletter from our website.

6.1.3. Survey

The survey is shown in Table 1 and consists of 11 statements that must be rated using a 1 to 5 Likert scale, where 1 means "strongly disagree" and 5 "strongly agree". The first 4 statements deal with the *need to improve* the current review process. Statements 5–8 assess possible *resistances* for the adoption of a reviewer reputation system. Finally, statements 9–11 evaluate whether the participants think that *a reputation system* might mitigate some of the issues.

6.1.4. Results and discussion

The survey was filled out by 36 researchers and the results are summarized in Table 2. Note that not all the statements have the same number of answers since participants only had to rate the statements regarding the roles in which they had experience (as authors, reviewers and/or editors).

As we expected, authors feel that the quality and fairness of the review process can be sensibly improved. Reviewers seem to think their work is not correctly rewarded or acknowledged, and editors have difficulties finding good reviewers, but these results are not as strong as the former ones.

Regarding resistances, both authors and reviewers support the idea of a reputation system. There is more controversy regarding anonymity: 14 reviewers agree or strongly agree that they would need anonymity to participate in the system, while 22 remain neutral or disagree. However, all participants strongly agree they would like to rate other's reviews.

Finally, all participants believe that a reviewer reputation system could have a positive impact in the review process. Editors would have an additional source of information to find better reviewers; the quality and fairness of the reviews could be sensible improved; and the work of the reviewers would be properly recognized.

Overall, these results, although preliminary, encouraged us to further explore our idea and perform the interviews that we describe in the following section.

6.2. Editors interviews

After assessing the interest in our proposal, we performed a series of interviews to different types of editors following the Lean Startup methodology (Maurya, 2012). The goal of the *Problem Interviews* is to better understand the problem editors face during a peer review process and how they deal with them. This information is essential as a first step to define the functional requirements of our software solution. *Solution Interviews*, on the other hand, are used to validate the value propositions of the different iterations of the design and development of our system with a user centered approach.

Methodologically, the interviews were semi-structured, aiding a better understanding of the topic at hand. They were selected using snowball sampling. It was concluded that this method was the most suitable approach since the context, particularly at the institutional level (e.g. journal editorial office, academic associations, university press), required the interviewer to gain access via personal recommendations to ensure the participation of institutional actors.

6.2.1. Problem interviews

We performed 19 problem interviews and obtained information about 5 journals, 6 conferences, 3 academic associations, 4 reviewers and 1 university press.

We identified that the most important problems editors face in the peer reviewing process (the ones mentioned more frequently or with a stronger emphasis) are:

- Finding suitable reviewers for each paper.
- Getting reviewers to accept the review task.
- Receiving the reviews on time.
- Obtaining good quality reviews.

We also found out that editors use different strategies to deal with these issues. For example, a conference organizer shared that, to deal with bad quality reviews and slow reviewers, they keep a list of reviewers to avoid. And a journal editor explained that he usually needs to send at least ten invitations to get enough reviewers for a paper.

6.2.2. Solution interviews

We carried out some initial usability sessions and interviews with two potential interested organizations: Ediciones Complutense[13] and Iberamia.[14] During these sessions, they tested our prototypes and helped us to improve our search tool for finding reviewers. The current state of the tool, that was introduced in Section 5, provides three main functionalities:

1. **An interface to search reviewers** who meet some criteria.
2. **Reviewer reliability statistics** such as how often they review on time, reputation ratings and acceptance ratio.
3. **Access to previous review reports** if they are publicly available (open reviews).

We have also identified new requirements aimed at reducing even more the effort required to find suitable reviewers such as getting access to a larger pool of reviewers or getting automatic recommendations. We will deal with these requests in future versions of DecSci.

6.3. Scalability and cost analysis

We have performed a third kind of evaluation: a cost analysis of the main activities performed by the system. Thus, we can see in Table 3 the five main operations analyzed, and the cost of running those operations over the Ethereum network. Note that other metrics such as the latency are not dependent on our code. Instead, they depend on the Ethereum network congestion and on the commission the user is willing to pay to prioritize their transaction.

In Ethereum, every operation performed implies a cost, i.e. a commission to be paid by the user, for the miners to perform the requested operation. In practice, validating and performing those operations requires a certain amount of computational work performed by miners (see Section 2). The amount of computation required by an operation is named *gas*, and it is paid in cryptocurrency; in Ethereum, with its token Ether (abbreviated ETH). From the user approach, gas ultimately translates into money and the amount of gas depends on the size and type of each operation.

The five operations analyzed are:

Table 3
Cost analysis.

Function	Gas	Cost (ETH)[a]	Cost ($)[b]
Send Paper	114,812	0.0016	$3.86
Assign Reviewers	58,707	0.0009	$2.15
Accept Review	23,971	0.0004	$0.92
Send Review	149,760	0.0025	$6.12
Send Rating	94,122	0.0017	$4.08

[a]Using the recommended slow gas price at https://www.ethgasstation.info/.
[b]ETH price (June 16th 2021) $2400.

- Send Paper: to submit an article by the author
- Assign Reviewers: to assign potential reviewers to a certain article, by the editor
- Accept Review: to accept the invitation to review a certain article, by the reviewer
- Send Review: to submit the finished review of the article, by the reviewer
- Send Rating: to submit a rating of a review, by any actor qualified to assess reviews (which may be any user)

Thus, we can observe that some operations may have an excessive price for certain users, which may deter them from using the system. For instance, spending $6 to submit a review may be unacceptable, unless the reviewer is monetarily rewarded by the review. Similarly, submitting a review rating for $4 may limit the ratings received.

There are multiple paths to tackle the excessive transaction cost. First, the issue of excessive transaction cost is a well-known issue within the Ethereum community, which affects all Ethereum-powered apps. This damages adoption and limits scalability for the whole ecosystem. In order to tackle it, a new version of the system, named Ethereum 2.0, is expected to facilitate scalability and notably reduce the price of transactions.

The price of transactions varies depending on multiple factors, such as Gas price (which depends on network congestion) and Ethereum price (which depends on the cryptocurrency market). Thus, both factors are highly volatile and difficult to predict. Code optimization, to reduce gas cost per operation, could reduce transaction cost if scalability or price issues where a concern. However, our software can be deployed in alternative Ethereum-based networks such as Bloxberg. Bloxberg[15] (Kleinfercher, Vengadasalam, & Lawton, 2020) is a research infrastructure relying on a global blockchain maintained by a consortium of universities and research organizations. In the Bloxberg blockchain, gas price is free, since the block validation operations ("mining") is performed by the consortium academic institutions.

There is still the question if, regardless of price, the Ethereum network could handle the expected throughput of the proposed system. Ethereum has a throughput of more than 1M transactions per day (de Azevedo Sousa et al., 2021), and that is before the expected improvements of the forthcoming Ethereum 2.0. Moreover, the limit of transactions and gas per block can be increased by miners. Nowadays, the limit is 15M gas per block (MyCrypto, 2021), i.e. more that a hundred of our most expensive transactions every block (or 13 s). Every year 14M reviews are performed (Johnson, Watkinson, & Mabe, 2018), so the equivalent number per day (38 K) could be reasonable handled by the current version of Ethereum, even as one of the many applications available in the network. Still, Bloxberg, as mentioned above, does not suffer the mining limitations of the Ethereum network (Kleinfercher et al., 2020), as its expected throughput is calculated as hundreds of time higher than current Ethereum. Thus, scalability should not be a serious matter for the proposed system, especially in blockchain networks dedicated to academic purposes.

7. Interoperability challenges

The Decentralized Science system proposal, as described in Sections 3 and 4 , and implemented in the proof-of-concept from Section 5.1, is overly ambitious. In practical terms, information systems are not built on the void, but on an existing context of platforms, technologies, third-parties and legacy systems. In fact, one of the criticisms made to blockchain and decentralized technologies is their lack of interoperability with both existing centralized systems, and other decentralized applications. Thus, there are multiple interoperability challenges related to the Decentralized Science ecosystem:

- Integration with Publication Management Software
- Facilitate adoption by third-party web applications
- Interoperability with other reviewer platforms
- Interoperability with other blockchain applications

In this section, we explain how the architecture of the proposed system is appropriate to overcome interoperability issues in all those aspects. These will be covered briefly in the following subsections.
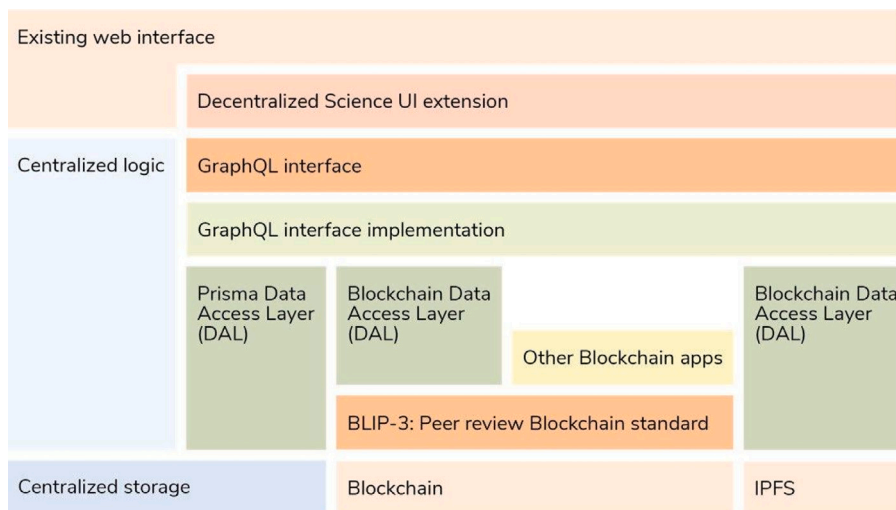
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[15] https://bloxberg.org

Fig. 5. Decentralized Science ecosystem's architecture (With BLIP3 standard).

7.1. Integration with publication management software

The submission, review and publishing of academic papers is currently supported by software Publication Management Systems. Big publishers such as Elsevier or Springer use their own proprietary software while OJS Open Source software is the most adopted solution among smaller publishers and independent journals accounting for tenths of thousands of journals.[16]

Our architecture proposal aims to facilitate the interoperability with such existing and widely used systems. It relies on providing a GUI for the search of relevant peer reviewers (Fig. 4), which can be integrated with the publication management software as a web component. Concretely, our software is integrated with OJS system. The database of this software (centralized storage in Fig. 5) is then accessed to get information about the reviewers. The left half of Fig. 5 depicts the interactions between the centralized software, storage and web interface (OJS), and DecSci GUI, logic and decentralized technologies. A public API (GraphQL interface in Fig. 5) to interact with the centralized and decentralized parts of the system is also provided, as described in the following section.

7.2. Enabling third-party adoption: GraphQL public API

Public APIs are often used by internet services to provide access and functionalities to third parties and promote interoperability among independent systems. Decentralized Science provides such API using a GraphQL interface.[17] This interface defines the data types of the system and how these data types can be composed.[18] For instance, providing the fields a peer review report record can have, or stating that users in our system have a list of such review reports that they authored.This GraphQL API enables other applications to interact with Decentralized Science. For instance, other GUIs could be implemented, as well as services such as enhanced reviewer search engines.

7.3. Integration with reviewer platforms

The publication of peer review reports and information is a key part of large online reviewer communities such as Publons (Rajpert-De Meyts et al., 2016) (with more than 200.000 reviewers) or post-publication peer review services such as Faculty of 1000 (F1000) (Wets, Weedon, & Velterop, 2003).

Our architecture proposes to inter-operate with such communities by allowing reviewers to import the reviews from Publons and F1000Research communities. The Bloxberg's blockchain peer-review-app implements such import functionality, bringing the needed interoperability to the system.

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[16] e.g. being used by 44% of library-published, faculty-driven journals (Johnson et al., 2018)

[17] It is worth mentioning that the project The Graph (https://thegraph.com) is providing GraphQL APIs for existing Ethereum blockchain applications (Kaandorp, 2021)

[18] Details of DecSci's graphql schema can be found online in: https://github.com/DecentralizedScience/Prototype/blob/master/server/src/schema.graphql

7.4. Interoperability with other blockchain applications

There are several active blockchain projects that aim to share peer review information to improve recognition of reviewers' curriculum (e.g. Bloxberg's (Kleinfercher et al., 2020) peer-review-app (bloxberg, 2020)), provide incentives for peer reviewers (e.g. Eureka (Niya et al., 2019)), or enable post publication peer review (e.g. Orvium (Orvium, 2021)), among others (Mackey, Shah, Miyachi, Short, & Clauson, 2019). Several of these projects are collaborating in the definition of a standard for the registration of Peer Review information (Tenorio-Fornés et al., 2020) in Bloxberg's infrastructure. As mentioned above, Bloxberg is an Ethereum-based blockchain which provides infrastructure for scientific research.

Different blockchain projects such as Bitcoin or Ethereum have standardization processes to agree on shared libraries, interfaces and protocols. Some examples of these standards are the inclusion of Bitcoin multi-signature wallets (BIP[19] 67) or the standardization of Ethereum tokens (ERC[20]-20).

In the Bloxberg network, a blockchain for academic applications, such standards take the name of Bloxberg Improvement Proposals or BLIP. The standardization effort for registering peer reviews in the Bloxberg blockchain is named BLIP-3.[21] It aims to generalize the initial implementation of Bloxberg's peer-review-app to: enable a diversity of actors and applications to write and read the data; facilitate sharing information and avoid information silos; and promote interoperability with existing standards (such as ORCID, or Crossref), decentralized applications (such as Decentralized Science, peer-review-app, PeerMiles, or Orvium), and important peer reviewer communities (such as Publons or F1000Research). Fig. 5 shows how a shared blockchain interface would enable the interoperability across several decentralized applications.

8. Discussion and concluding remarks

8.1. Reviewing the proposal

There is a social consensus on the need to share and make scientific knowledge accessible, especially when it has been financed with public funds (Schiltz, 2018). Most researchers at universities and research centers do not charge for publishing their discoveries, and yet their institutions are forced to pay large amounts of money to publishers in order to access those same publications they produce. On the other hand, the evolution of technology has facilitated the distribution and access to scientific knowledge to the point of questioning the traditional role of publishers and other intermediaries in the chain of scientific publication.

In this work, we have presented *Decentralized Science* (DecSci), an interoperable platform based on decentralized technologies that aims to provide an alternative publication model to enhance the transparency and accountability of the peer review and publication processes. Overall, the main contributions of this work can be summarized in:

- We show how blockchain and IPFS technologies enable novel decentralized systems for managing the Peer Review process.
- An Open Access decentralized infrastructure for Peer Review is technically and practically feasible, after multiple evaluations and prototypes.
- We validate how the academic community (reviewers and journal editors) shows interest to improve quality, fairness and recognition through a system like the one proposed.
- We validate how the proposed MVP provides value to reviewers and journal editors, addressing their need to get recognition and improve their selection of peer reviewers respectively.
- A hybrid architecture tackles interoperability challenges of decentralized/centralized systems.

We proceed to detail the main contributions, followed by an overview of the main challenges this proposal and its underlying technologies may face.

In particular, we propose to decentralize three core parts of the Peer Review and publication process: (1) the selection and recognition of the peer reviewers using a transparent reputation model, (2) the distribution of the academic papers through the IPFS peer-to-peer network, and (3) the transparency of the whole peer review process, from submission to publication, using blockchain technologies.

We carried out a short survey to tentatively assess the possible interest and resistances that a transparent reputation system for reviewers could arise. The initial results were quite positive since most of the participants think the quality and fairness of the review process can be sensibly improved, and that a reputation model could be an interesting solution in which they would be willing to participate.

The core of the system is based on *smart contracts* that enforce a transparent review process, storing the different steps as time-stamped transactions in the blockchain: paper submission, review proposal and acceptance, review submission, author's resubmission of improved versions of the paper, and ratings of the reviewers. We have developed a proof-of-concept prototype based on Ethereum smart contracts to enable these interactions. We have also developed a minimum viable product of a search engine to find reviewers that provides relevant metrics (e.g. reviewer timeliness, acceptance ratio), and enables open access to previous peer review reports. Using our web interface, journal editors may be able to find suitable reviewers in different platforms (centralized and decentralized),

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[19] Bitcoin Improvement Proposal
[20] Ethereum Request for Comments
[21] Bloxberg Improvement Proposal 3

using a unified interface. This interface was developed in collaboration with editors of academic journals by means of different interviews to identify and provide a solution to their needs.

We have also addressed the challenges that a decentralized platform such as DecSci must face to facilitate interoperability with existing software systems. These challenges include the integration with existing publication management software, the adoption by third-party applications, the interoperability with other reviewer platforms, and with other blockchain applications.

8.2. Open challenges

Furthermore, the use of decentralized technologies introduces additional scalability and cost challenges. The *scalability* of blockchain systems is an issue in very large systems and, in fact, the Ethereum network has already experience congestion episodes, leading to dramatic increases of latency and transaction costs (Faqir-Rhazoui, Ariza-Garzón, Arroyo, & Hassan, 2021). However, there are currently many different approaches being developed and adopted (Zhou, Huang, Zheng, & Bian, 2020) that make us feel optimistic about this matter. Besides, the Ethereum network currently handles hundreds of thousands of transactions daily, which is more than enough for our system requirements even in the long term. Blockchains are also often criticized for their transaction *costs*, but second layer solution should not only solve scalability issues in the future but also drastically reduce these costs.

Another important challenge for open and decentralized systems is the *management of identities*. Addressing potential problems by sybil identities (i.e. multiple identities controlled by a single entity) and identity verification (to avoid frauds and impersonations) are some of the most common issues to manage identities. To address them, there exist different strategies used in fields such as Social Networks (Al-Qurishi et al., 2017), Internet of Things (Zhang, Liang, Lu, & Shen, 2014), distributed currencies (Nakamoto, 2008), or Self-Sovereign identities (Mühle, Grüner, Gayvoronskaya, & Meinel, 2018), as well as from academic oriented services and applications such as ORCID (Bilder, 2011), or Peerage of Science (Hettyey et al., 2012).

The use of blockchain technologies can also bring transparency to peer reviewing and help to expose and reduce bad practices (Mohan, 2019) such as *fraud* and abuse in the peer review process to maximize profits (Bowman, 2014) or benefit academic curricula (Teixeira da Silva, 2017). However, it also introduces new concerns regarding the detection of fake identities and fake peer reviews that could break the integrity of the reviewing process, and damage the quality and fairness of academic publishing.

The low levels of *inclusiveness* and *usability* are other important limitations of current blockchain technologies. Reducing the complexities of decentralized systems to users is one of the biggest design challenges to reduce the barriers of adoption of blockchain solutions. *Data availability* and *stewardship* of decentralized information systems is an additional challenge, as without proper policies, important data could be lost.

Despite the existing challenges, the use of decentralized technologies can introduce disruptive innovations and improvements for academic publication and peer reviewing. Decentralized Science introduces a proposal of one of such systems, with a technological proof-of-concept and a minimum viable product implementations, evaluations of the proposal, and an architecture to facilitate the integration with existing and widely used technologies. The level of adoption of these decentralized technologies and their real impact remains to be seen. To support it, the paper introduces a perspective where an ecosystem of existing centralized technologies and emergent decentralized solutions work together to deliver the promises of blockchain applications for academia.

CRediT authorship contribution statement

Ámbar Tenorio-Fornés: Conceptualization, Software, Formal analysis, Funding acquisition, Investigation, Writing – original draft, Writing – review & editing. **Elena Pérez Tirador:** Conceptualization, Software, Formal analysis, Investigation, Writing – original draft. **Antonio A. Sánchez-Ruiz:** Conceptualization, Investigation, Supervision, Writing – original draft, Writing – review & editing. **Samer Hassan:** Conceptualization, Formal analysis, Funding acquisition, Supervision, Investigation, Writing – original draft, Writing – review & editing.

Declaration of competing interest

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