To Survey the adoption of crypto-economically incentivized "good behavior" and governance models in the interest of projects crowdsourced from the global scientific community for scientific & RTD commons

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Abstract

In this paper we review existing literature and conduct an analysis, in which we aim to determine the requirements of an open science ecosystem and compared these requirements with the characteristic of blockchain technology (BT) to see if the technology suits as an infrastructure for a new platform which serves as the basis for the establishment a new digital scientific community. We begin by reviewing literature in the scientific space concerned with highlighting some of the known shortcomings that exist in various processes in academia. This is followed by the categorisation of the different visions that exist among scientists today in regard to the direction and future of open science. We then give a brief summary and introduction into some core terms and concepts associated with Blochian technology before carrying out a detailed analysis on some existing, state of the art BT inspired projects which currently are using blockchain to streamline different processes in academia such as peer-review, the irreproducibility of results and open access of information to name just a few. We then finally conclude our findings from the analysis of these different projects to extract the most promising features of BT to scope our own blockchain inspired digital economy which integrates a digital token aswell as a robust governance model to effectively decentralise the current scientific infrastructure by making it more transparent and accessible to the masses. The final topic in this paper shall serve as starting points for future research to foster the BT for open science and beyond, especially in the long-term

1.0 Introduction

Since its inception a little over a decade ago through the digital cryptocurrency "Bitcoin ", distributed ledger technology, (DLT) more commonly phrased "blockchain technology" (BT) has established a powerful and accelerated trajectory into global industries **[1]**. We see this constantly in todays' world, where there is a parabolic growth in different sectors of industry such as finance, medicine and manufacturing that are beginning to "re-invent" themselves by adapting with the times and adopting this emerging technology, ultimately using it to profit from its bundle of unique characteristics **[2]**, all of which we will be intricately discussing in this paper. We focus on the adoption and integration for BT in open-science and by reviewing current literature, and research that is currently being conducted in this "niche" space and we aim to comprehensively Survey the adoption of crypto-economically incentivized "good behavior" and governance models in the interest of projects crowdsourced from the global scientific community for scientific & RTD commons.

1.1 Why Blockchain technology?

Currently, the most notable attention that the entry BT space has received has been through the news and digital media about the rapid development of crypto currencies [3]. These include Bitcoin, Ethereum, Cardano, Polkadot and Solana, which are among the most prominent cryptocurrencies today, seeing momentous market capitalization in the Billions of dollars **[4]**. Although the Fraunhofer institute for science and technical trend analysis (INT) in Germany posted a study **[5]** conveying that currently BT can mostly be found in financial applications, the promise for this technology doesn't stop there. Investors are beginning to realize the value and prowess of the underlying technology and there are to date, many other already existing blockchain – based applications in the public sector such as crowdfunding, supply-chain optimization, authentication and voting services **[2]**, the list goes on. As stated in the original Bitcoin Whitepaper **[6]** the original vision for this distributed ledger technology was to enable the ability that "would allow online payments to be sent directly from one party to another without going through a financial institution". In other words, that the exchange of value "units" of some asset without the need of the oversight of intermediaries or 3rd parties. However, the original "bitcoin" is quite primitive by today's standards in terms of what is currently capable and being achieved with BT. The original bitcoin was a P2P "only" digital currency, and it still remains that today, albeit with some slight extra features that are generally only concerned with infrastructure improvements around things such as scalability [**13]**. In essence bitcoin only barley scratches the surface of the of what is possible with distributed ledger technology on a global scale

This all stems back to the fact that the definition and collected vision of what the future of blockchain should be has rapidly changed and shifted direction since the inception of so called "smart contracts". The birth of the first programmable blockchain Ethereum **[8],** redefined what could be done in the space and truly for the first time, it made it possible to map any medium of exchange or asset to the decentralized P2P vision that bitcoin originally enacted. In other words, the Ethereum network could not only cater for the trust-less transfer of digitally tokenized money, but also any form or definition of the word "asset". Because this is all hosted in a virtual and digital space, there is no bounds to what the definition of the unit or medium of exchange is. For instance, allowing individuals to offer and sell their digital assets such as art, data from sensors on a marketplace or even enabling property owners to transfer their land without a notary **[7].** The birth of smart contracts opened up an entirely new world in the realm of (BT). Commonly cited alterative applications of this technology include using on-blockchain, or on-chain digital assets to represent custom currencies and financial instruments (colored coins) **(see appendix)**, the ownership of an underlying physical device (smart property), non-fungible assets such as domain names (Namecoin), as well as more complex applications involving having digital assets being directly controlled by a piece of code implementing arbitrary rules (smart contracts) or even blockchain-based decentralized autonomous organizations (DAOs) **[8].** The "smart contract" running on top of the underlying blockchain gives the user the ability to effectively streamline processes that involve multiple parties to arrive at consensus or decision on some outcome. All of this is because of computer code which does not operate off emotion by rather pure and data driven logic. One of the core principles of (BT) even above that of "decentralization" is the concept of immutability. The immutable nature of (BT) yields append-only functions, coupled with an entirely viewable record of all transactions **[2]** from genesis (first mined block). Thus (BT) is able to guarantee transparency for all users in any system.

1.2 Fostering blockchain in open science

The thought of this is very promising when viewed or considered in terms of the application in the academic space and in this paper, this is largely what we will be focusing on. The transparency, trust and decentralization have the possibility to enable researchers to build their own digital open ecosystem or economy for research, communication and much more that are all in line with the philosophy of open science **(Table 1)**. However, there needs to be a credible need for the implementation of a new technology to redefine and organize the structure of the space. What are the current standards in academia and open science and are they efficient, do they need change, or more specifically do they need remodeling? Besides the reproducibility of experiments **[9][12]**, one of the main promised of the application of (BT) in open science is towards trust-orientated problems such as the sometimes profit driven behavior that is going on in the publishing and peer-review sector **[10]**, not to mention the restrictions of the free and open access to scientific publications, patents and research **[11]**.

Having said this, there is more that could potentially be gained from the application of BT in open science. Although the outcomes can be considered promising in relation to the decentralization of the trust issue problems such as the peer review process and free open access science, these alone are not enough in terms of substantial revelations or innovations to generate any meaningful impact in regard to valuable "change" in the space in relation to how things operate. (DLT) offers the opportunity to shift the status quo, which boasts incredibly unique and creative transformations in the space, and this is all because BT stands out from other systems in its exceptional technical architecture, which allows the technology to get adapted for a variety of use cases. The idea of merging two industries namely, crypto & science together, yields the possibility and opportunity to create unique business models and incentives for users or entire communities. This gives way to the creation of an entirely digital ecosystem where concepts like crowdfunding, crowdsourcing **[14]**, incentivized consensus, liquid governance, tokenomics, prediction markets and arbitration **[1] (see appendix for said terms)** can all be merged to define a virtual scientific community where the distribution of wealth and community drive is shared amongst all network participants while maintaining and incredible standard of open access and valid "information" in all of its defined forms.

As this is a new and only recently emerging niche in the entirety of the blockchain industry and although there are already some scientific sources which have conducted studies in this area, much of the available information is "grey literature" **[2]**. However, in the coming sections we specifically focus exploring in more detail the main problems in science by comprehensively scrutinizing a handful of insightful papers that have been written solely on the highlighting some of the shortcomings in open science and academia. This will be followed by a detailed comparison of the current frameworks and existing structures in both traditional systems and decentralized systems which implement blockchain in some sense (DAO's), both on a general level and in terms of efficiently governing the peer review process, academic information sharing and crowdsourcing etc. Once the core problems and existing practices have been well established, we will cover a quick review of some blockchain fundamentals such as consensus, governance, cryptography and more in order to be able to understand some of the architecture of this technology. The last two sections in the report will consist of reviewing already existing literature that has already examined this niche space as well as proposing some of our own unique possible solutions for applications of BT in open science. All of this will be done in pursuit of determining if the characteristics of (BT) align with the goals and needs of an open science infrastructure.

2.0 The problem today: An unequal world in science

Universality is a fundamental principle of science. In other words, only results that can be discussed, challenged and where appropriate, tested/reproduced by others should qualify as scientific [**2**]. Science, as an institution of "organized criticism", can therefore only function properly if research results are made openly available to the community so that they can be submitted to the test and scrutiny of other researchers. This is a common frame of mind in the scientific community and there exists many papers which are solely dedicated to making known the problems surrounding open access of scientific information **[38][49][40].** In many cases researchers seem to be aware that things aren't perfect but such is the same in any form of industry so why should we lust for change? This article **[42]** highlights some of the common problems that exist in the scientific and academic community such as the restricted access to published science, poor quality of peer-review sometimes in offensive manners, the unrewarding nature of the peer-review work and the lack of "set in place" barriers to prevent the replication and falsification of research. We want to disclaim that allocations such as these are not common place and we merely highlight some past examples as a basis to construct our evidence for argument. We do not do this in any way to brutally critique the scientific industry as such claims would be unfounded.

2.1 Inconsistencies in the peer-review process

Such an example of the problems concerned with peer-review can be found in this article **[41]** which shows a case where a peer reviewer stole text for his own chemistry book and got sanctioned by his journal. Also, the quality of peer-review depends on the quality of the peer-reviewers. Peer-reviewers are typically selected based on their expertise in the areas of research associated with the submitted manuscripts. Although being a peer-reviewer is considered a sometimes-frustrating job **[47]** due to the tough hours of other underpaid work, communication between authors, editors and reviewers determines the eventual success of the publication. There does not exist today any sort of robust communication networks to cater for such a line of connected components to facilitate the secure and seamless information transfer which we could hope to solve with Blockchain technology. Also, as this publication points out **[48]** some peer-reviewers are too young with limited experience, not all are equally skilled and very few have had formal training and assessment methods for peer-review. This is not to mention a growing body of quantitative evidence which shows in some rare cases violations of objectivity and bias in the entire process for reasons beyond that of author attributes such as language, institutional affiliation, nationality and other attributes such as gender and sexuality **[49]**. Occasionally reviewers' comments are rude or malicious as demonstrated by this study **[50]**. These are some of the shortcomings of one of the largest components in the traditional academic infrastructure.

2.2 Irreproducibility of scientific results

Another common difficulty that exists throughout the entire scientific community is concerned with the inability to consistently reproduce scientific results. Although this is no secret, these papers give evidence that publishing reproducible analyses is a long-standing widespread challenge for the scientific community, funding bodies and also publishers **[44][45][46]**. This problem affects all disciplines of science **(see section 5.1)** and there is surprisingly little work that is making ground in terms of a definitive solution. It is unfortunate because reproducibility is a key property of any scientific endeavor, enabling the progressive structuring of knowledge into innovation through a process of knowledge integration and reuse in future studies to come. Whether how much science is unreproducible because of chance or the because of the fact that the initial results have been overclaimed or even falsified is another question. However, In the case of the pharmaceutical industry, companies systematically attempt to replicate studies with a potential for clinical application and as shown in this study **[9]** the total prevalence of irreproducible preclinical studies exceeds 50%, where each replication requiring between 500,000 – 2,000,000 $ investment for the company involved. This eventuality is undesirable and needless, especially for the investors and a collaborative effort needs to be promoted and established in order to address inefficiencies like these in the open science community

2.3 Scientific Publication Paywalls

In 2016, the EU Ministers of science and innovation, assembled in the Competitiveness Council, resolved that all European scientific publications should be immediately accessible by 2020 which unfortunately is not the case today. Sceintific Journal such as Springer continue to charge a "pay per view" fee to read some scientific papers. This subscription-based model of scientific publication arose during a certain point in history when research articles required substantial typesetting, layout design and printing, when hardcopies of journals needed to be sent globally. While the publishing process need services as it transitions from print to digital, distribution methods have fundamentally changed. There doesn't exist anymore as much of a valid reason to maintain a subscription-based business model for scientific publishing in the digital world, where Open Access dissemination is maximizing the impact, visibility, and efficiency of the whole research process.. Publishers should offer services that assist scientists in reviewing, editing, disseminating, and linking their work, and they should charge a reasonable price for these services in a transparent manner. On page 6 of the 2015 'Science Europe Principles on Open Access Publisher Services' **[43],** the minimum requirements for services required from publishers are spelled forth. These are only a few examples of typical events that show convey the tendency to lean toward centralization in the conventional scientific community. One conclusion we might get from some of these issues is that new research builds on established results from prior work. The chain that builds new scientific discoveries on previously established findings can only function properly if all research results are made publicly accessible to the scientific community. Having said that, it should be emphasized that in recent years, significant attempts have been made to remove some of the publishing paywalls that are preventing fractions of the scientific community and society from accessing research **[10].** However, if open science is to thrive and prosper in the coming years, this trend must continue and accelerate, since selling access to new and current research findings is fundamentally opposed to the scientific ethos. **[41].**

2.4 Proposing a Blockchain based solution

Researchers and research funders have a shared responsibility to care for the scientific system. The 2003 Berlin Declaration **[42]** is a powerful representation of the scientific community's desire to reclaim control of the laws regulating scientific information dissemination. Furthermore, in 2013, Science Europe set criteria for the transition to Open Access [43], although overall progress has been gradual. As indicated in **section 2.2**, the EU Ministers of Science and Innovation announced that all European scientific papers should be promptly available by 2020, which as we mentioned is not the situation today. However, in light of these continual attempts to enhance the space, I believe that more radical alternatives should be considered. Remember that the purpose of this work is to analyze the existing state of the infrastructure in the scientific space and to determine whether the use of BT might help optimize and change the way things are done. As a result, we must investigate if the technology is suitable as a basis upon which to build. It is critical to comprehend the "matrix" as a whole since there are various needs and features that already complement each other between the standard open scientific framework and a BT suggested framework. For example, it is useful or needed for many functions like providing a "trail" of research so that there is "no censorship" possible in a blockchain network to provide a trustworthy environment. Such an immutable and transparent trail of information could also contribute to solving the irreproducibility problem not to mention the ability to define more robust communication channels between researchers, publishers and funders. And the BC could be the root whereby all collective scientific information would be linked and openly available on a distributed ledger **[44].** Other shortcomings of the current infrastructure, such as sometimes unskilled peer-reviewers, the unrewarding peer-review process itself, and the occasional occurrences of malicious peer-review feedback, could both be addressed by a BT network through the implementation of an incentivized governance model similar to that of a proof-of-stake consensus mechanism as proposed by the Ethereum 2.0 network **[8],** whereby an issued utility token could serve as the basis of an economic model such that good behaviour and hard work is strongly incentivized through "token rewards" whilst the opposite is strongly discouraged through the implementation slashing protocols **[51].** This is explained in more detail in **section 6.1 and 6.2.** In this section we highlight all of these inefficiencies and shortcomings of traditional science and probed some of the possibilities that blockchain could bring to the table in order to make the academic space more fluid.

3.0 traditional & decentralized organizations for governing open science

In this section we will briefly describe the philosophy and ethos behind open science and also, the existing problems in science that it can mitigate. Furthermore, we will be doing an analysis in order to determine what requirements have to be met to establish a technical ecosystem that is in line with the principles of open science and thus we will compare the benefits and shortcoming of centralized and decentralized systems in order to see if a blockchain based infrastructure suits as a suitable foundation for an open science ecosystem.

3.1 The philosophy and visions of open science

There are several definitions of what open science is but there doesn't exist one universal definition that is generally accepted amongst the scientific community. However, this paper gives **[2]** gives a good definition, FOSTER. That is that "Open science is the practice of science in such a way that others can collaborate and contribute, where research processes are freely available under terms that enable the reuse, redistribution and reproduction of the research and its underlying data and methods." It is important to note that there are other definitions in the literature such as the "open definition" **[51]** and one from The Organisation For Economic Co-operation and Development (OECD) **[52]**. In essence open science is an umbrella term for multiple assumptions or "schools of thought" that exist about how the future of knowledge creation and will work **[15]**. In this section we will briefly discuss open science in its chances and challenges to provide a common point of definition from that we will link the possibilities of BT to the fundamental concept of open science. Fecher and Frieskike **[15]** wrote an insightful paper that classified open science into five different schools of thought that summarise the central goals that people have in open science which we can see in **Table 1** below.

	Description	
	Assumption	**Goal**
Democratic & Pragmatic Schools	The access to knowledge is unequally distributed Knowledge creation could be more efficient if Scientists worked together	Making knowledge freely available for everyone Making the process of knowledge creation more Efficient and goal orientated
Public School	Science needs to be made accessible to the public	Making science accessible for citizens
Infrastructure School	Efficient research depends on the available tools And applications	Creating openly available platforms, tools and services For scientists
Measurement School	Scientific contributions today need more Alternative impact measurements	Developing alternative metric system for scientific impact
Community SACHOOL	Science requires all voices to be heard and a Committed community	Ensuring more diversity and inclusion in scholarly conservations

Table 1: The main schools of through in open science as described in Fecher and Frieskike **[15].**

One insightful paper **[2]** explores in great detail these five schools and provide an interesting analysis in regard to the requirements of that a new framework would need to implement an infrastructure for open science. Today's communication technologies have opened the way to practice open science in detail and the methods for producing, storing, sharing and accessing information have been progressing **[53].** Opening research outside that of the scientific community provides among other things, the chance to get valuable feedback from other researchers for work in progress. One existing example of this is the platform Open Science Framework (OSF) **[54]**. As we mentioned above one interesting thing about a decentralised approach such as that of a blockchain implemented decentralised autonomous organisation DAO is that if the scientific community and non-experts are able to access research data while it is still in progress to provide feedback in the form of possible mistakes and potential improvements. This approach would also create the possibility to find solutions to specific problems by having more eyes looking at the work **[55].** However open science still must overcome significant obstacles in different dimensions to get widely applied. Most of the research points mentioned here require changes in the research processes, habits and behaviours or researchers. For example, the traditional workflow of a typical researcher needs to change as researchers do not publicly discuss different topic about their work before the final publication **[2]**. Research most of the time, is taking place in a closed institutional framework without the integration of individuals from the outside. These barriers need to be put down in order to meet the ethos of open science as outline in **Table 1.** Around the whole open science discussion, a legislative framework has to be developed, but not only on the national level; it has to be international to set the global rules for the disclosure of incoming and outgoing data and also to protect the rights of all people involved. It is also a discussion of how the crediting of contributions is working fairly when researchers are creating micro-contributions **[16]** in addition to traditional publications

3.2 Infrastructure requirements for an open science framework

With the underlying five schools of through as proposed by Fecher and Fireside **[15]**, here we will summarise the common requirements that is shared among all schools in order to identify some of the general requirements for an open science infrastructure and see if these align with the characteristics of BT. This is done in order to really see some of the similarities between the needs for such an infrastructure and the characteristics that blockchain can provide.

As we can see from the relevant literature and **Table 1**, one essential requirement of an open science infrastructure is to provide a collaborative environment, which means that researchers and also nonexperts are able to work together, author collaboratively and share information and materials on different projects [56]. The performance in a research team compared to a single effort is far more effective and efficient on different levels. For example, better quality, higher productivity and fewer errors by additional review bodies. The requirement of open data and open access are supporting the collaborative environment while they address different scientific problems. Open access portrays free access to knowledge, for example scientific publications [57]. As we discussed in section 2.2 research publications are often behind a paywall with continuously increasing costs [58] that can hinder researchers. This paper [57] describes the access to knowledge as a necessity for human development. Another aspect of open data addresses the reuse of published scientific data [59]. Often and academic third party like a publisher holds the rights, so the scientific community is not allowed to reuse this data without permission [60].

1. As a result, another criterion of an open scientific infrastructure should be reusability, which prevents the waste of resources for gathering previously collected data and allows for synergies between researchers and their activities [60]. Unfortunately, as long as the law is followed, everyone should be allowed to openly express their opinions without fear of being banned. According to this study [61], the same should be true in science. In an open research environment, there should not be a centralized institution in charge of scientific infrastructure, but rather communal administration. This necessitates the creation of governance models that serve as a foundation for the user community. As we shall see in section 3.2, the notion of decentralized autonomous organizations may be a solution to this.

2. Another requirement is to provide an identification and reputation system (which we discuss further in section 5.1) that can identify researchers and other ecosystem participants and link them to their contributions so that all valuable work and invested effort of all contributors can be appropriately credited. This would also make it possible to reward micro-contributions. Other procedures should be put in place to assess an individual's impact factor or reputation. The "h-index" to develop reputation is one such example [62]. This already exists in the conventional scientific domain, but it has to be expanded and redesigned in order to be converted to a BT-based platform.

3. The last basic criteria we found is that every part of a technological infrastructure be expandable in order to ensure the overall ecosystem's sustainability [63]. Extensibility is essential, particularly in today's digital era, as computer technology evolves so quickly and produces more efficient new tools on a regular basis. Overall, it enables the ecosystem's community to constantly update and enhance

the individual components, eliminating the need for expensive and time-consuming alternatives in the long run. As we shall see later in this study (section 6.1), liquid governance mechanisms in permissioned blockchains like Polkadot provide strong democratic voting methods for platform updates.

3.2 Comparison of centralised & Decentralised systems

Some of the needs for an open scientific environment were described above. Many of these seem to speak to both digitized cooperation and process decentralization rather than the current, more centralized and unconnected form, exhibited in the conventional scientific environment. It is true that the major source of flaws such as corruption or the emergence of inefficiencies in processes is due to "this" centralization of things in any form of infrastructure or organization. The key distinction between centralized and decentralized communication networks is who has control over the network itself. A single administrator maintains complete control over all areas of the organization or network in a centralized system. Decentralized organizational structures, on the other hand, often have numerous persons accountable for making business choices; they depend on a team or democratic atmosphere at various levels in the firm [64]. When we look at academia, we see that there is not one final ecosystem or network where information is produced, processed, and dispersed. One of the issues is that you don't define "academia." Stakeholders in "academia" include almost everyone [65], from university students and faculty to corporations, organizations, and financiers that collaborate with institutions. In other words, there are several centralized bodies that function as a single authority and, when united, produce the scientific ecosystem that we know today.

Modern colleges have shifted their focus to operating as typical enterprises in more profit-oriented ways. In recent decades, for example, many colleges have shifted toward a more hierarchical and centralized organization [66]. As we established in section 2, the publishing business has too much influence over the circulation of scientific content. Many academic journals use antiquated publication procedures as well. In many circumstances, this results in a separation or barrier between communication [67]. In compared to modern technology, obsolete systems and ways of operation are often more cumbersome and limited. Despite the advantages of accepting current technology, certain businesses, such as academic publishing, have been sluggish to absorb them. Springer Nature product manager Stephen Cornelius writes in this Medium essay [68] that after decades of technical improvement, "academic publication remains trapped with people who were hired when it first went online." These include only posting papers as PDFs, waiting for articles to be published in issues, and the difficulty of transporting data between different processing platforms. All of these difficulties are not exclusive to the publishing industry, but rather to academia as a whole. Lack of innovation and disjointed concentration of things creates a communication barrier between many persons and groups in academia, and there is currently no uniform, worldwide infrastructure that serves as the cornerstone of research. The industry's outmoded and centralized structure is at the foundation of this. As is the purpose of this study, one potential answer to reorganization is via blockchain, where a new digital ecosystem might be built through a platform. Decentralized autonomous organizations are a new form of business model that seems to align with many of the open scientific aspirations outlined in Table 1.

A decentralized autonomous organization (DAO) is a blockchain idea that aspires to decentralize and automate cooperative governance using smart contracts and tokenization [60]. Smart contracts provide for the enforcement of rules and choices, while token holders make the final decisions, with voting power proportionate to the amount of tokens they own. A DAO, as opposed to a typical organization, is a flat organization with little or no administrative structure. It is essentially an effort to construct a digital democracy in the absence of an organization. In the open scientific business, for example, a DAO is an open-source smart contract-based organization that accumulates research funding and resources. The supporters would be allowed to select how the research funds should be used "along" with the researchers [61]. One such advantage, as highlighted in this paper, is that there would be no economic barriers to reading or writing scientific publications, and reviewers and authors would be incentivized to play their role in the system, such that stakeholders with skin in the game are rewarded proportionally to the value they provide. However, we must recognize that implementing a DAO will not address all of our problems. This is due to the fact that, apart from being a new and somewhat unexplored idea, the most significant deficiency of a DAO is undoubtedly scalability and lifespan in the context of expansion. Not to mention that with each new member added to the DAO, the voting power of current members is diminished. Furthermore, as token supply grows, new members participating in the DAO will have less and fewer voting rights [61]. Other limitations of DAOs include their lack of legal personhood, which precludes them from owning property or entering into contracts in most countries, restricting their usage for conventional cooperative objectives [62]. However, there are methods to mitigate some of these problems, and significant study is being conducted, particularly in the blockchain arena, on DAOs, as we shall see in sections 5.1 and 6.1.

4.0 Blockchain Technology, Infrastructure Overview and Application

Although we could spend this entire paper discussing and describing the key elements of BT, this is sadly beyond the scope of this research review. Rather, in this part, we want to present a quick summary of blockchain's primary features and functions in order to get some basic information about it before moving on to the next sections, which are more blockchain oriented and need some basic knowledge to grasp. We will be able to evaluate and contrast the needs of an open research infrastructure with the features of BT as a result of this.

The word "blockchain" is a "umbrella term." In today's culture, there are widely divergent conceptions of what blockchain is among non-experts. Some people associate blockchain with "bitcoin," while others believe it is just a distributed database. While there does exist remnants of truth in both of these statements, when talking about BT, it's incredibly important to first realize the distributed ledger technology that underpins the entire thing. Distributed ledger technology employs separate systems known as nodes to carry out the process of recording, distributing, and, most crucially, syncing transactions in a decentralized database or network [16]. A Blockchain works in a similar way, but it organizes data into discrete "blocks" that are also cryptographically secure due to the use of hashing (section 4.2). The blocks are also chronologically time-stamped, and in more current blockchains known as 3rd gen blockchains (see appendix), different types of consensus methods, governance protocols, and smart contracts are often used [2][17].

Finally, one of the fundamental distinctions between a blockchain and a distributed ledger is that, unlike a distributed ledger, a blockchain not only partitions data to various nodes, but each node keeps the complete database. As early as 1991, Stuart Haber and Scott Stornetta devised a fundamental architecture for blockchain technology [18]. Their original and even modified architectures, however, had several basic weaknesses, such as the famed double spending issue [19], which is effectively a data duplication problem (see appendix). Furthermore, their initial architecture was based on the demand for trustworthy third-party validators. It wasn't until 2008, when a person using the pseudonym "Satoshi Nakamoto" produced a whitepaper proposing a peer-to-peer digital currency, that these weaknesses were overcome. A Bitcoin double spend is defined as a bad actor sending a duplicate of one transaction in order to make the copy look valid while keeping the original or deleting the first transaction entirely [20]. Because digital information is more readily reproduced, this is both conceivable and harmful for Bitcoin or any other digital money. Double-spending is prohibited in the Bitcoin network by combining complementary security features of the blockchain network and its decentralized network of miners to validate transactions before they are added to the blockchain [21]. So it is this component of on-chain governance and economic incentivization that distinguishes blockchain technology from other distributed networks such as distributed databases.

When a transaction is validated by at least six separate miners, it is attached to a block and becomes legitimate, but transactions that do not match this condition are simply ignored and erased from memory. Although blockchain technology provides nothing new in terms of its individual aspects, the combination of these features, such as decentralization, immutability, transparency, and cryptographic hashing, is unique and aids in avoiding the double spending issue [6]. A blockchain network functions without the need of a centralized server. In such a system, all transactions are validated by decentralized nodes and recorded in so-called blocks with a timestamp. The size limit of blocks varies based on the blockchain, however in order to foster decentralization, block capacity sizes across blockchains are often quite minimal, such as 1MB in the bitcoin network. This is due to the fact that a blockchain with a much larger block capacity would necessitate increasingly higher node hardware requirements in order to effectively run a node, and as a result, it drastically reduces anyone's ability to run a full node on their machine, thereby creating a barrier to entry within the network.

After studying the available literature, it is clear that there are several alternative characterizations of BT nowadays [22][23]. Therefore, in order to keep this section, brief we provide a compressed summary of the main properties which list all of the core and relevant characteristics of BT in regards to its application in the open science space.

4.1 Decentralization

Decentralization is one of the most distinct characteristics of any blockchain. Recall that a blockchain is a distributed and redundant peer-to-peer system of nodes which each store the whole blockchain database **[2]**. This decentralization eliminates a potential single point of failure and effectively removes the dependency of a central authority that has to be "trusted" in order to execute different processes. We can describe a type of network in relation to the number of edges that a particular node has. In a distributed network every node has roughly the same number of edges and there are more routes in which nodes can connect with each other. This means that the topology of the network does not contain nodes in central or privileged positions **[24]**. This gives distributed networks the special property whereby the failure of one or few nodes still leaves the network connected and being able to operate consistently, allowing all nodes to communicate with each other. Consider **Figure1** below.

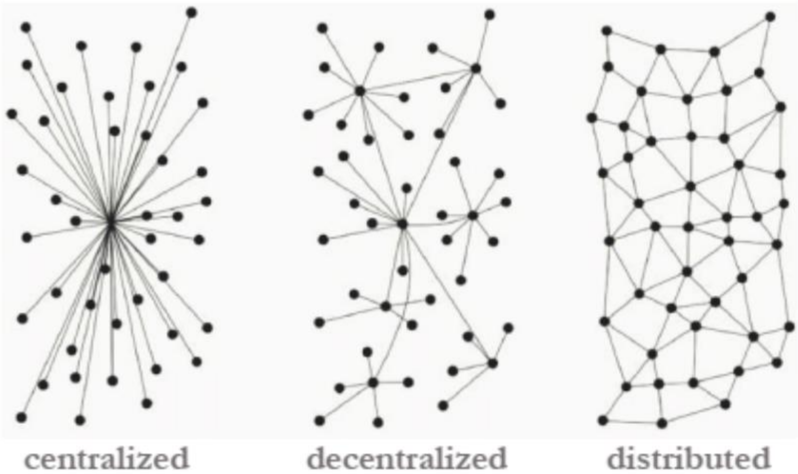

Figure1: Various network topologies (Baran 1964)

Though often used interchangeably, decentralized and distributed networks are not the same. Decentralized networks are built from a hierarchy of nodes and nodes at the bottom of this hierarchy only have a single connection to the network. Failure of a few nodes in a decentralized network still leaves several connected components of nodes that will be able to communicate with each other (but not with nodes in a different component). In a BT context the decentralized layout of the networks topology has incredible security benefits such that if one of even a few "bad actors" try to orchestrate a malicious attack for example a 51% attack **(appendix)** then the rest of the network will still be able to operate and disregard the bad actors due to all of the nodes being interconnected.

4.2 Cryptographic Hashing

“Hashing” is the process of converting an input of any length into a fixed size string of text using a mathematical function **[25]**. This means that any string of text, no matter how long, can be converted into a fixed size array of numbers and letters. On the highest level this is what a hash function is. Cryptographic hashes have three crucial properties that provide useful security in terms of BT. They are:

- **Hiding**
    - Given H(x), it is computationally infeasible to determine (x)
- **Collision Resistant**
    - Given that (x) != (y), it is computationally infeasible to find H(x) == H(y)
- **Puzzle Friendly**
    - The easiest way to calculate H(x) is to calculate H(x).

There are many different formulas or algorithms that can be used for cryptographic hashing **[26]** some of which include the SHA-256, MD2, CRC32 and RipeMD128 hashing algorithms. In BT the most used hashing algorithm is the SHA-256 algorithm because of its special property that it is incredibly collision resistant. Since the hash of some arbitrary data always returns the same output as long as the input remains unchanged, then in the context of blockchain, the entire log of transactional data in each block is hashed and this output hash is included as a transaction itself in the proceeding block. Consider the diagram below where each the hash of the data in each block is taken using the H(x) notation

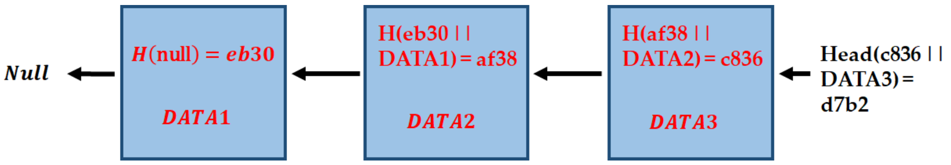

Figure2: Showing the use of hashing (hash pointers) in a simple blockchain

As we can see from the diagram above due to this hashed connection a chronological chain gets created **[6]** whereby each block also contains information about all of the preceding through the included hash of its data at the new blocks header**.** Besides the blockchain consensus mechanism **(see below),** hashing ensures that any bit of information in the complete chain cannot be altered in any way because such a change would affect one specific hash, and as a result each consecutive hash would also become altered thus rendering the chain invalid **[27].** we can see this in the modified diagram below

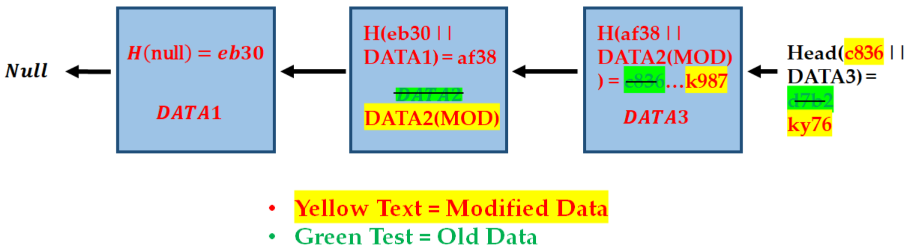

Figure3: Demonstrating how chronological hashing prevents data manipulation in a simple blockchain

Hashing not only provides security and upholds the immutability of a blockchain but it also has tremendous data storage optimization characteristics. For large files that need to be stored off-chain for example in IPFS (interplanetary file system) **(see appendix)** hashing provides the ability to create unique identifiers of these files that can be included on-chain as a reference point which can be queried at any time in order to fetch the contents of that hash. For more information about the hashing process see the following references **[6][28][29]**.

4.3 Timestamping & Immutability

Timestamping is not an idea that appeared in the 21st century for the first time. In fact, people have historically searched for ways to securely track and authenticate documents. Every record in a blockchain gets chronologically timestamped. Doing so provides traceability, transparency and not to mention a full transaction history for the users **[6].** Since the process of timestamping is an automated code-driven process, this is one way that removes the need for a trusted party to consistently and reliably keep track of information. The combination of timestamping along with the cryptographic hashing explained above can be used as a Proof-Of-Existence for certain information at a particular time **[30].** Many blockchain explorers exist today that allow anyone to come on and see all transactions ever executed on a blockchain. One such example is Etherscan **[31]**, an Ethereum blockchain explorer.

Also, data, once initially stored on the blockchain cannot be altered or deleted in any way, we call this feature "append-only." The cryptographic hashing and decentralized validation process ensure that the only exception to this rule are specific network attacks such as the infamous 51% attack **[32].** However, to put things into context, the Ethereum blockchain has a market capitalization of nearly 300 billion dollars. Therefore, in order for a successful 51% attack to be launched on the Ethereum network, the attackers would have to accumulate over half of the current Ethereum supply which at the time of writing this is 118 million ethers. At todays prices the attacker(s) would need to spend roughly 250 billion dollars in order to be able to take over the network which is nearly impossible by today's standards.

4.4 Consensus Mechanisms

Consensus mechanisms are arguably the most important feature of any blockchain. This is because they define how users validate transactions among each other **[27]**. Since the Bitcoin blockchain and its Proof-Of-Work based consensus mechanism, many new and unique methods have been developed and implemented in new blockchains. The two most commonly used consensus mechanisms are Proof-Of-Work and Proof-Of-Stake.

- **PoW** is the consensus algorithm used in bitcoin. Its core idea is to allocate the accounting rights and rewards through the hashing power competition among the nodes. Based on the information of the previous block, the different nodes calculate the specific solution of a mathematical problem. It's difficult to solve the math's problem. The math's problem is far more complex but the technical details are not within the scope of what we want to capture in this paper in short it requires running millions of computations until a miner's software generates and hash output with a certain amount of leading zeros which is dictated by the current difficulty at the time. The first node that solves this math problem can create the next block and get a certain amount of bitcoin reward. Satoshi Nakamoto used HashCash to design this mathematics problem in bitcoin **[33].**

- **Proof of Stake (PoS)** is an alternative to PoW as it is more energy efficient objective of both being the same, for example, to reach a consensus within the blockchain, method of achieving it is completely different. Proof of Stake consensus algorithm uses a selection process that is pseudorandom in nature to pick the validator of the subsequent block from the existing nodes. The process is based on a mix of several factors which include randomization and staking age along the node's wealth. In Proof of Stake consensus mechanism, blocks are said to be "forged" rather than being termed as mined **[34].** While in PoW, the block which first solves complex problem mines the next block and receives rewards whereas in PoS, the individual node which creates the next block is selected based on how much they have "staked" in comparison to other competitor nodes **[35]**. stake is usually based on the number of coins the network node has for the particular blockchain it is attempting to mine. In these systems, the transaction fee is generally the reward, and users who want to be among the participants in the forging process need to lock their stake (a certain amount of coins) in a network. The chances of a node to be selected to forge the next block as the validator depends on the size of their stake, which means that the chances of the node to win the next block increases as its stake increases. But these selection criteria are biased, as the network will be dominated by the single node with the maximum stake. To overcome this issue, more methods are added to the selection process, two of them being "randomized block selection" and "coin age selection" but we will not discuss these here.

4.5 Blockchain Governance

Every blockchain can also get characterized through its access and governance protocols be it permissionless or permissioned **[36] (see appendix)**. One major aspect of any POS based blockchain application is indeed this concept of governance. Governance is a very broad topic but in short it describes how changes to a decentralized ecosystem are both proposed and put into place in a fair and decentralized manner **[37]**. All systems must adapt or die, and blockchains are no exception to this universal truth. One of the benefits of centralization in any system is the simplicity of administering change, the confidence that someone can correct a problem or add a new feature. However, in order to be long-term viable, systems must decentralize. Blockchains itself challenge existing worldviews, and in order to do so, they require a mechanism for evolution **[86]**. Blockchains began as a mechanism to represent financial transactions but rapidly extended to express zero-knowledge processes or abstract logic **[37].** Nobody knows how people will use blockchains in the future, but creating a new one for each new concept is not sustainable. Although for larger blockchain ecosystems such as Cardano, Polkadot and Ethereum the idea and necessity of governance is very important as it is the only way in which true democracy can be achieved for decentralized decision making.

Note, that the characteristics mentioned above are not exclusive to BT. As mentioned in the introduction, there exist other approaches that also have one or more of these properties. This section primarily served as a very brief introduction to some of the core underlying features that make up a general blockchain. It is important to have some notion of these rather complex concepts in order to not only understand the inner workings of a blockchain but also to understand how their implementation in an open science framework could be beneficial.

5.0 Existing blockchain open science platforms

Now that we firmly understand some of the shortcoming of traditional science, the need for change in the academic space and also the potential that the blockchain technology can offer as a way to effectively remodel and redefine the current standards within the industry, we can finally examine state of the art projects that currently exist which all implement blockchain in an open science ecosystem. In this section we will briefly summaries noteworthy projects and how they implement blockchain to achieve desired goals that largely stem from the five main schools of thought outlined in **section 3.2**. Note that their currently doesn't exist "one" project that solves everything by proposing a completely digital open science ecosystem that decentralizes everything, but rather many of the projects that we will be looking tend to only solve open or few sub problems such as reproducibility or transparency of evidence for example. Hence, we will conclude this literature review in **section 6.0** to use the information we've learned to propose possible next steps in regard to establishing an open science platform with a bigger vison that will strive to be a digital economy itself.

5.1 Key Open Science Blockchain Projects

To create an outline of the current research, I have read and analyzed research papers concepts and applications of two already existing blockchain open science frameworks **[70][71][93]** as well as a summary of the findings from **[2]**. However, for a robust analysis two projects is not enough to capture the entirety of the work that is happening in this niche space. Thus, finds from this paper **[2]** will also be discussed in this section. From looking at may existing applications today it is evident that the goals of some of these decentralized platforms are tightly aligned with the different views of the five different schools of though in open science from **section 3.2**. Since it is an early research phase, there is little literature about open science in combination with BT, but nonetheless, there are still exciting promising concepts, ideas, discussions and approaches that we should describe and highlight. A man called Vikram Dhillon wrote an article **[70]** and also an insightful book **[71]** about blockchain frameworks for open science. In the relevant chapter they talk about the reproducibility crisis **[72]** and the rare publication of negative results. Dhillon states that the BT has the potential to mitigate the crisis. They use a clinical trial as a practical example and define a workflow making the complete research process transparent whilst protecting the critical data of patients**.** Dhillon proposes a simplified workflow of an erroneous research method for dealing with positive and negative data resulting from the pressures in academia **[71].** In this model reputation is scarified in pursuit of highly demanding and attractive drug targets which ultimately do not translate well into clinical trials and lead to economic waste. Essentially his proposal aims to make clinical trial data publicly available on the blockchain with the implementation of colored coins **[73], (see appendix)** which allows for the attachment of metadata to the blockchain. He highlights three essential components of the model which can be seen in **Figure 4** below. They are also outlined from his book as:

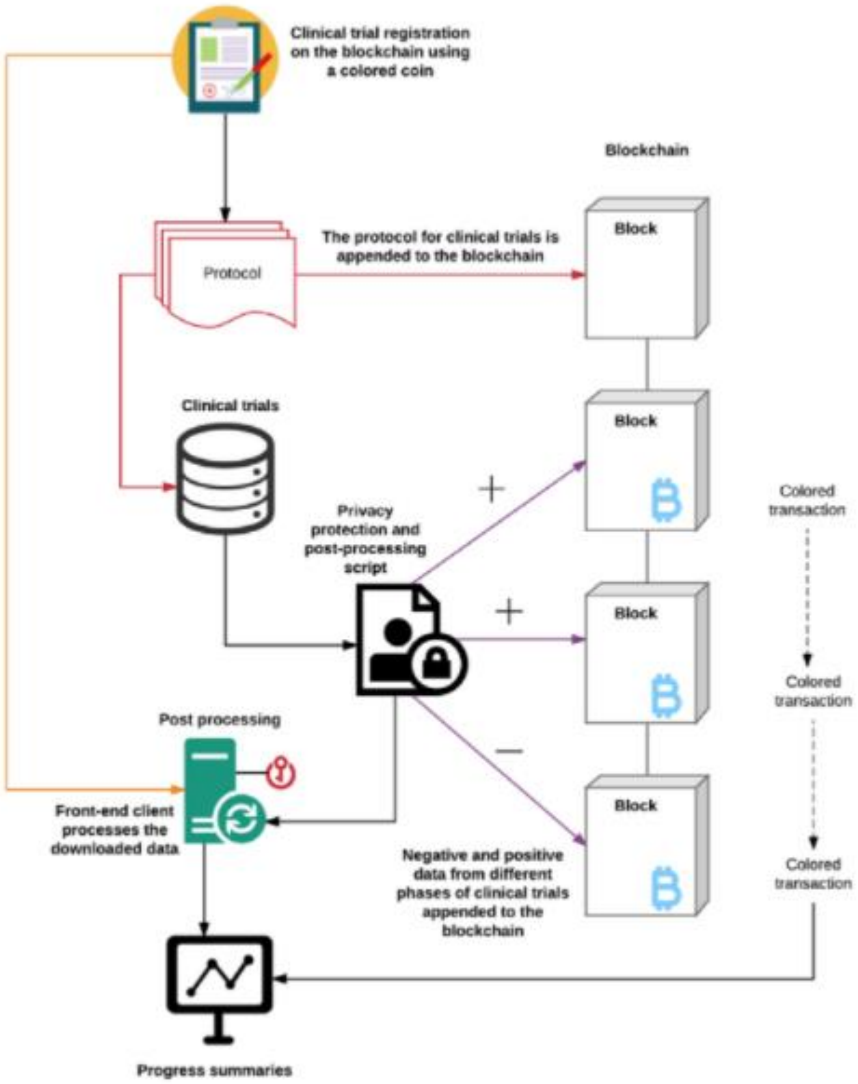

Figure 4: Schematic design proposal for Blockchain based clinical trial platform

- **Coloring scheme:** The encoding method by the colored coin data is encoded or decoded from the blockchain.
- **Asset metadata:** This represents the actual metadata attached to a colored transaction that gets stored in the blockchain. The bitcoin-colored coins protocol allows for the attachment of a potentially unlimited amount of metadata to a colored transaction, by using torrents that provide a decentralized way to share and store data.
- **Rule engine:** In the past, the metadata just contained static information added to colored coins. Recently, however, a new rules section has been added that encodes an extra layer of logic supported by our rule engine that unlocks smart contracts' functionality to colored coins. Currently four types of rules are supported, we will discuss these below.

The generalized syntax is given below for the metadata that can be added to a colored transaction.

```
{
   metadata: {...Static data goes here...},
   rules: {...Rule definitions go here...}
}
```

Dillon raises to key rules from the rule engine that are important to understand. The expiration rule and the minter rule. The expiration rule is used to loan an asset and it dictates the life span of an asset. After expiration, the asset returns to the last output that has a valid expiration. Conversely the minter rule grants a recipient permission to issue more of the same asset. Therefore, the minter receiving colored coins can further issue more colored coins to others on the network. We can see that the concept of blockchain economics **[74]** plays an integral role to both the incentivization and decentralization and governance of the entire process. Implementing BT allows for the transparency of information and the immutable nature of the data can allow for the establishment of linked connections between historical and new data to both maintain the integrity of data and to reward cited contributors. This is furthered by the introduction of tokenomics to the system through colored coins where researchers are incentivized to provide excellent data for the hope of a token reward. This system could greatly mitigate the chance of bad results. Although Dhillon's model does not include any form of slashing protocol, I would like to mention that staking in combination with slashing would provide the most effective method in my opinion to discourage lacking research data. This is because researchers with "skin in the game" could potentially loose their staked assets for acting lazily or malicious. Dhillon's model is surprisingly simple yet effective. Further to their research Dhillon also proposes to apply their approach to implement a blockchain based reputation system with an API as a reward for researchers and an indicator for the quality of contributions **[71].** In his book he outlines a simple model which describes this system. Dhillon notes that the reputation system emerged as a property of design from the introduction of colored coins and expiration rule. In the design a counting mechanism is derived from the evaluator function **[72]** which enables the rewarding of researchers who have been proactive in sending periodic updates to the blockchain. The counting mechanism allows for the appending of metadata to the Blochian through colored coins such that it can be tracked and referenced on chain. Each time research sends updates with verified data the counting mechanism increase their on-chain reputation. A diagram of Dhillon's design is given below

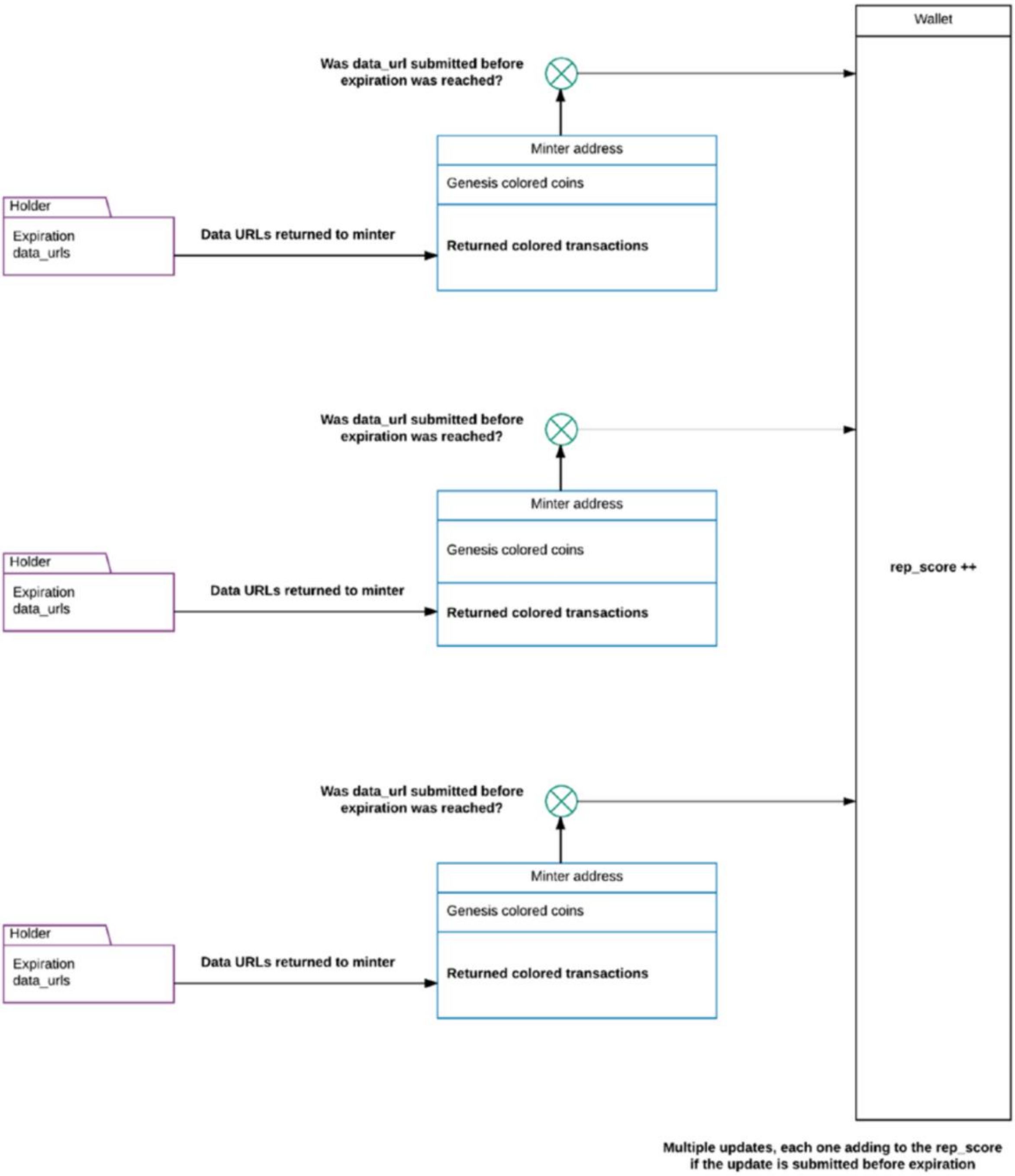

Figure 5: Schematic design proposal a blockchain based reputation system

The evaluator function checks for an expiration rule and if the colored coins transactions made by the holder contain the URLS's corresponding to updates in the on-chain metadata. If and only if these two conditions are met, the pep score is updated for the holder's wallet. Dhillon also notes how the **rep_score** can be referenced in a "blockchain agnostic" manner from external services and API calls. Although not implemented in his design document, one final interesting feature that Dhillon mentions is that of blockchain based prediction markets, where mainly, experts try to predict a specific outcome like the potential of reproducibility of an experiment **[75].** To create incentive to participate, users get rewarded for the right prediction. In his book Dhillon mentions that the Proceedings of the National Academy of Sciences **(PNAS) [89]** study suggests that predication markets can be used to decide which scientific studies should be priorities in replication efforts due to their uncertainty. However, in the study they do warn that prediction markets will not reliably predict which individual findings are accurate, but they can be used to estimate the credibility of current findings and make an ordered queue of studies to be replicated. An article by Andy Extance **[76]** contains similar statements to Dhillon's work saying that the BT could potentially enhance the current replication situation in science. However, although the work by Dhillon is one of the more fleshed out research efforts that can be found it is not without its flaws.

Recall in **section 3.2** we outlined the five main schools of thought as summarized by **[15].** These different schools result in a clash of opinion among the scientific community as to what the vision of open science should be. Dhillon's views seem to be tightly aligned with that of the democratic school, focusing only on data availability and transparency. We can see here with Dhillon's proposal that his solution is not an ultimate end all be all fix to all of the problem sin academia but rather he focusses septically on his area, pharmaceuticals. His ideals are focused on the transparency of evidence and data more so than anything else. This specificity could potentially be to his disadvantage in terms of adoption because his ideas cannot be applied to all areas of science. As well as this some of his proposals are underwhelming in my opinion. This can be shown through the use of colored coins as the basis for his blockchains scripting language instead of a more turning complete smart contract programming language such a Solidity **[91]**. Although colored coins allow Dhillon to do all he needs the larger question at had is, "is it sustainable?", A key component to any digital platform is the ability to be extensible as we mentioned in **section 3.2**, being able to update and adapt with the times. Primitive languages such as colored coins will most definitely provide a roadblock in the years to come when more robust and visionary ideas are proposed. On this topic, his model also doesn't provide a governance model to allow for the democratic voting on the updating od the framework. These are just some of the shortcomings of Dhillon's proposal. However, lets now look at another existing project which attempts to optimize the peer-review prices with blockchain integration

5.2 Blockchain-based Peer Review Infrastructure Proposal

As we outlined in **section 3.1** Scientific research activity is reaching a staggering growth rate, introducing new and compounding existing challenges regarding the quality of peer-review, rise of predatory journals **[77]** and larger issues involving academic integrity and fraud stemming from the increased pressure to publish. I this section we will review a design proposal for a governance framework which unlike Dhillon's implementation is focused specifically on blockchain based scientific publishing. The main authors of the proposal paper **[93]** are Tim K. Mackey and Neal Shah. Mackey and Shah's proposal builds on already existing approaches to the decentralization of scientific publishing offered by the platforms "Orvium" **[78]** and "EUREKA" **[79]** but differs from those examples by focusing on architectural framework that integrates and augments processes preformed by traditional publishers and scientific journals in lieu of creating a new blockchain based publishing platform or journal entity. As stated in the proposal paper the goal of the framework is to enhance transparency and integrity of publishing through shared governance between publishers' scientists and the public by mapping the publication workflow to blockchain architecture while being agnostic to a specific publisher. Before we get into the analysis of Makey and Shah's proposal we should first look at the organizational structure of the scientific publication industry in its current state

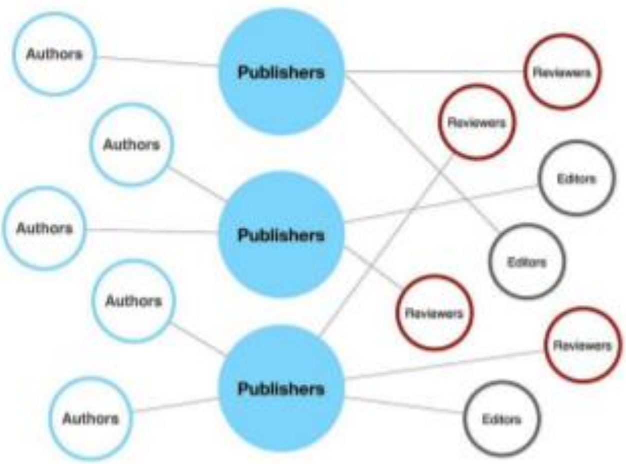

Figure 6: Organizational structure of the traditional scientific publishing industry **[93]**

The above image shows the centralized nature of publication industry. If we for a second, think of the entire industry as a network, then we can see that every single node is connected and dependent on the publisher nodes. In a traditional centralized network this means that there is only one single point of failure, in other words the publishers have in a sense control over the entire industry. They can publish what they want, charge as much fees as they want. And no one can effectively stop them because of the publishers cease to exist then no one will be able to publish any research. Now the diagram below shows how the organizational structure of the publication industry would look in a decentralized manner.

Figure 7: Decentralized organization of the publishing industry implemented with BT **[93]**

This is the conceptual diagram from Makey's and Shah's paper showing the distribution of the network. The implementation of BT, the nodes are now interconnected in such a way where there is not one point of failure, everything is sufficiently decentralized. Thus, the network is efficiently able to operate in the circumstance where on central node fails as outlined in the byzantine fault problem **[80] (see appendix)**. In the paper, Makey and Shah state that they choose blockchain technology over other technologies such as cloud computing and other traditional technologies because their framework requires data provenance of journal submission history, process-based workflow, validation of participating users transparency and the support for distributed networks. They claim that although other technologies exist that can enable all of the above, it is the ability of blockchain to leverage cryptography, decentralized apps (DApps), smart contracts, and the ability to interact, store and publish data via on-chain and off chain approaches, that positions it as a unique combination of technological tools for the specific challenges that we outlined in **section 2.2** associated with scholarly publishing. Mackey and Shah's proposal aims to streamline a few core areas in the peer-review processes. Namely:

1. Enabling the better detection of issues related to unethical and potentially fraudulent practices in order to greatly improve the overall integrity of the publication process

2. Creating a more robust and effective and equitable publication and peer-review process (including better sharing of resources whilst enhancing quality and speed in peer-review)

3. Encouraging broader engagement in research for the public and citizen scientists and creating an environment enabling shared governance where communities reach consensus on the appropriate rules and norms of the academic publication process

After conducting the analysis of this proposal, we conclude that on a high level their framework seems to mainly address the challenges listed above by (1) improving the transparency and oversight of the submission, adjustification and publication history for manuscripts agnostic to specific journals or publishers. (2) By mapping publication workflows to smart contracts and token payments (3) by the inclusion of a community of citizen scientists in the shared governance and as peer-reviewers. (4) And lastly by creating a DAO **(section 3.3)** to enable decentralized and shared governance driven by validated nodes of users. A key design feature outlined in the proposal was that the proposed framework purposefully departs from other proposals as it does not decouple the governance process from traditional publishers and journals. In other words unlike many other blockchain peer-review platforms which are mostly their own, OA journals that just happened to interact with a Blockchain to essentially become a unique journal in their own right, Mackey and Shah's proposal focusses on using a consortium blockchain design which includes both elements of private permissioned and public blackchins **(see appendix)** which can include participation from existing journals and publishers that contribute together in a shared ecosystem with authors, reviewers and editors under shared governance principles. Before we analyze their decentralized academic publication flow, we will look at the schematic design diagram for their platform showing how all of the connected components such as the front end UI and the back end smart contract code interact with each other.

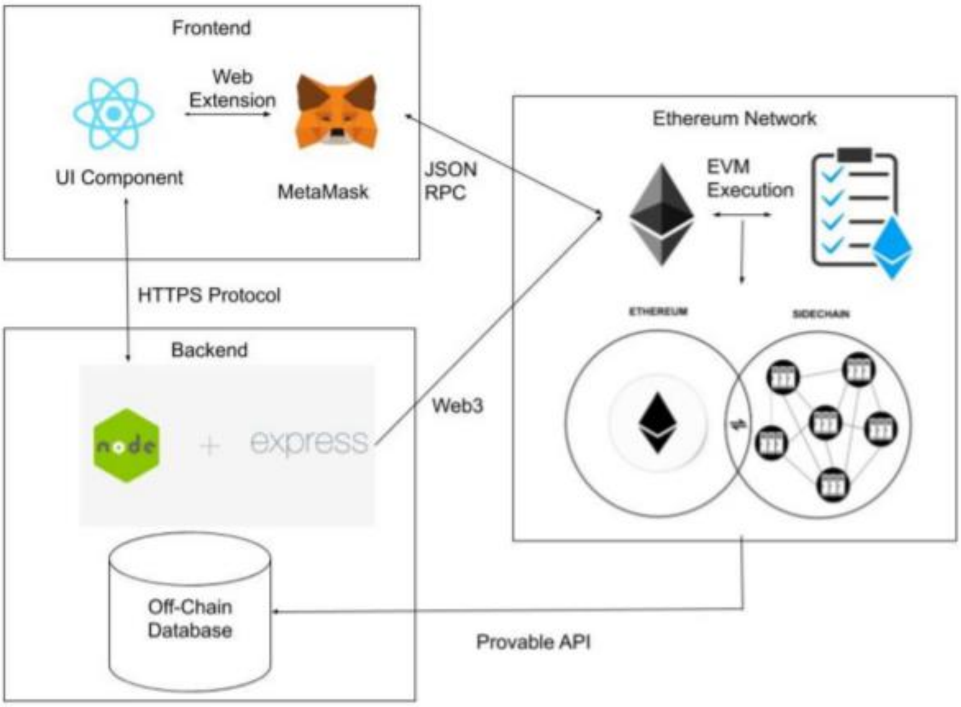

Figure 8: Overview of Technical Architecture of Proposed Governance Framework **[93]**

From **Figure 8** we can see that the publishing blockchain framework consists of a frontend component that is intended to be embedded within current journal and publication interfaces and utilizes Metamask **[81]** (an Ethereum based cryptocurrency wallet) in order to store user wallet information and sign on chain transactions through cryptography. The frontend component communicates with Node.js and Express blackened framework in order to access information from the off-chain database. The backend architecture communicates to the blockchain network through Web3.js **[82]**, which is an Ethereum and JavaScript API that can invoke the smart contract functionality, which ultimately determine the executable logic that occurs on the public Ethereum chain as well as the side chains **[83]** formed during the publication cycle. In total there are five separate stages to the publication process in Mackey and Shah'. **(For 82 & 83 see appendix)**

1. **Author Submission**
2. **Manuscript Handling**
3. **External Peer-review**
4. **Editorial Assessment**
5. **Production & Post Peer-review**

Author Submission

The first phase consists of manuscript submission to the existing journal frontend through an ORCID Member **[92]** web front publishing system. All submissions are created with a genesis block **(see appendix)** upon the first submission, which is then linked to subsequent submissions if the manuscript metadata matches. In their design Mackey & Shah propose that the author (identity validated by ORCID) submits the manuscript and submission metadata via the normal journal submission process with the data integration framework API transmitting the ORCID author identity and submission metadata to the Ethereum Network and the backend framework database. Editors or publishers in turn, may determine that a solicitation or invitation to submit is appropriate through this process

Phase 2: Manuscript Handling

In Phase 2, after the article has been submitted to a journal, the subsequent adjudication history remains in a private side-chain through different phases of the editorial and peer-review process. They propose that DAO participants of journals/publishers, handling editors, and reviewers collectively determine token costs for manuscript handling that can also be journal or publisher specific based on the specific terms of the publication process. Following deposit, the submission is handled by the journal's internal editorial staff or a pool of validated independent handling editors with at least two validating nodes (a publisher and handling editor) reaching consensus on deciding whether a submission is sent out for external review or rejected.

Phase 3: external peer-review

The third phase begins the process of external peer-review. In Mackey and Shahs' proposal a handling editor selects from a pool of DAO external peer-reviewers who are matched based on their research metadata and ORCID profiles or can be invited by handling editors if they are DAO validated members or can be subsequently validated following invitation. In addition to scientific reviewers, an optional citizen scientist can be chosen to assess implications of research from a public or patient centric perspective. A smart contract is executed to execute the logic for this. Once the review is complete and terms are met, tokens are deposited as payment to external reviewers

Phase 4: Editorial Assessment

The fourth phase is editorial assessment following external peer review. Decisions and recommendations made by the external reviewers are assessed by handling editor with a decision to accept, revise with minor or major revisions, or reject the manuscript on the basis of external review. Consensus is established by Proof Of Authority **[84]** with the majority of external reviewer and handling editor nodes reaching agreement. If a manuscript is rejected or subsequently withdrawn, the author pays the token cost for external review and the publisher pays the prorated token costs for handling editor's work up to that phase.

Phase 5: Production 7Post Peer-review

The last phase in Mackey and Shah's proposal marks initiation of the production phase. A smart contract executes the terms agreed upon and disclosed in **phase 1** above between the author and publisher or else another possibility that they propose is via a subsequent publication agreement between author and publisher when directly making a submission to the framework. If the author and publisher have agreed to non-OA (with copyright assigned to publisher), the submission token fee and all token fees for handling editor and external reviewers are automatically assigned to the journal. After acceptance, all blocks related to the adjudication history for the accepting journal are released to the public chain on the Ethereum network with a duplicate copy published to the backend database.

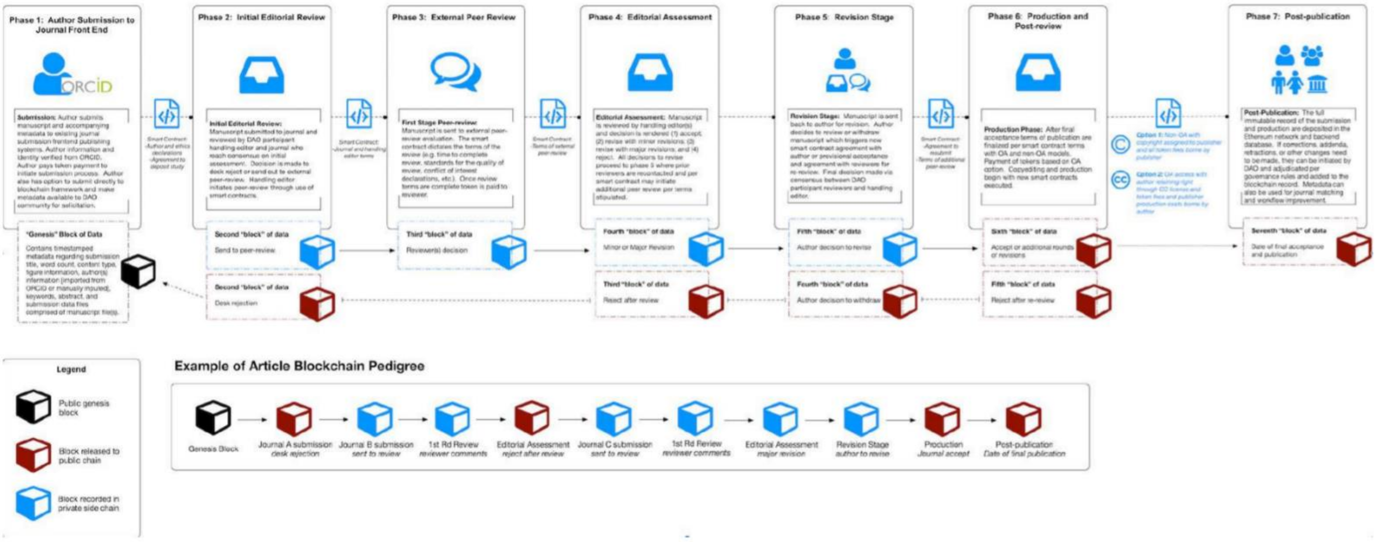

Figure 9: Overview of The Publication Workflow **[93]**

We can see Mackey & Shah's blockchain publication workflow in **Figure 9** above. We can see that the process starts with the creation of a genesis block and subsequent blocks of that are "chained" together to form the complete submission history pedigree for a manuscript.

5.2 Disadvantages of Blockchain & Current Existing BT Inspired Projects

The two projects discussed in this section are just two of many different research proposals that exist which all focus on the endeavor of combining blockchain technology with open science. We can see from the contrasting examples above that the application of BT in a scientific environment does show some prowess in terms of democratizing processes and making things more transparent and accessible in general. We can see from the above case studies that if for example, a researcher a researcher integrates BT continuously within the whole research cycle, it can be useful in every phase, also partially experimenting if it comes to tests of algorithms or evaluation of sensorial data. As shown, there are many varieties of using the technology in science to achieve a win-win situation for all stakeholders. In combination with sophisticated application design and development, it also is able to enable new usage models regarding research management, peer-reviewing, funding, and publishing.

However, the expectations must be realistic; BT is not a cure for all existing problems in science or an all-in-one solution. These two examples also pinpoint the conclusion from Fresker and Fakels **[15]** segregation of open science into the five different schools of thought. And that is that different groups within the scientific community have different visions of what the future of open science can be. We can see this here as Dhillon's paper focusses on the implementation of blockchain to make the reproducibility of scientific results more consistent through various techniques which we discussed in **section 5.1.** While on the other hand Mackey and Shahs proposal is concerned with making the peer review process more transparent. The point that we should take from this is that many of these blockchain orientated open science projects all seem to fall under one of these categories from the different schools of thought in that they are trying to solve one specific thing. There doesn't yet exist an endeavor that is focusing on the bigger picture that is, the pursuit of developing a completely new digital scientific economy that implements Blockchain to streamline the current scientific infrastructure by bundling solutions for all of these different areas such as peer-review, publication paywalls, irreproducibility, open access etc. into one decentralized scientific platform or marketplace. There is sufficient evidence for this in this paper **[68],** which carried out a review on over 50 different blockchain scientific projects and categorized them into the categories shown in figure 10 below

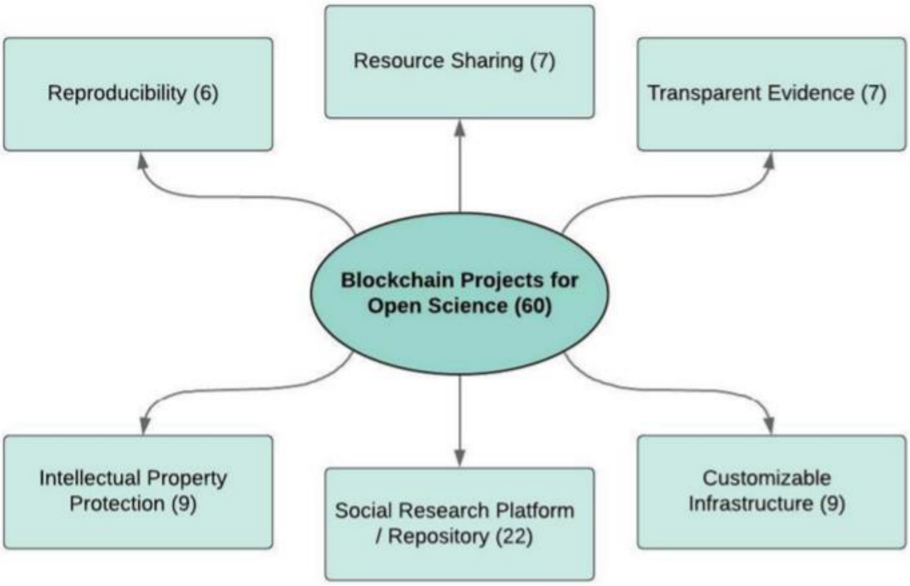

Figure 10: Categorization of scientific project implanting BT **[2]**

From the diagram above we can see that the research carried out by **[2]** concludes that most of the blockchain project sin open science seem to focus on refining specific and isolated areas in traditional academia, perhaps motivated by individuals who are experts in these said areas. Reproducibility, resource sharing, transparent evidence, intellectual property different components that contribute to some of the shortcomings in traditional academia.

This section highlights some of the research that is being to try and combat these failures by exploring current research, but we need to look into the future to see where this space is headed. Considering the acquired knowledge, I agree that the BT has a great potential to foster open science in various aspects. Examples are a new level of trust into systems and their transparency, traceability of digital assets, higher reproducibility, innovative citizen science projects, creative incentive methods, and a generally improved research quality. Especially the realizable openness of blockchain applications and the tamper-proof recording of all transactions in a system make this technology to a suitable thrustless infrastructure for open science. Currently there is does not exist any ambitious projects that promote the adoption of crypto-economically incentivized "good behavior" and governance models in the interest of projects crowdsourced from the global scientific community for scientific & RTD commons. This is not to mention that the technology is still in an early phase of its lifecycle and in many ambitious applications it can be concluded that it is not quite there yet. In the next section we will explore some future outlooks concerned with research in this space and we will probe a concept that we have developed which we will be exploring in much more detail in its own follow up research paper

6.0 Future Work & Blockchain Governance Model Proposal

We will conclude this literature review with a small section where we combine the knowledge gained in the last section to propose a more ambitious open science blockchain model that scopes the implementation of a robust governance model in order to establish a decentralized and democratic community with built in rules that govern the initiatives in the scientific community in order to facilitate processes in every area of science from peer-review to crowdfunding, research funding and more, all incentivized through the issuance of a digital scientific community token that allows individuals to establish a skin in the game in order to have community reputation and voting power in order to have a say in the development of a fully digital and decentralized global scientific economy. This section will effectively serve as the prelude to a follow up paper solely focused on the development and design philosophy of this new model. One Integral component of any decentralized model is that of governance. Governance is a very broad topic but in short it describes how changes to a decentralized ecosystem are both proposed and enacted **[85]**. Below we briefly introduce and explain the governance model proposed by Polkadot **[86]** where finally we conclude this section with a proposal of how such robust governance could be used to establish a fully decentralized scientific community.

5.1 Introducing Community Governance Through Polkadot

Blockchain governance frameworks have, so far, faced several problems. Forks split communities as well as software, and the dependence on security and adoption creates a zero-sum game where only one chain emerges. Coin voting **(see appendix)** is a good first step toward transparent, open, on-chain governance, but low turnouts make it susceptible to large voters controlling a vote. Even if a collective or a coin vote leads to an agreement, they lack usually the means to enact their decision; the true power still lies outside the protocol, for example with miners or validators. Just because a country holds elections, for example, doesn't mean people consider it a democracy; the system must include the means to enact the outcome. The same applies to blockchains. Coin voting is not sufficient if it is not binding **[86]**.

With Polkadot's main goal of uniting blockchains, it is designed so that users can make changes on-chain in a way that maintains and updates the system without forking. Users can make changes using several different options. Besides making it easy for users to propose changes, Polkadot provides the framework for users to build collective groups with certain permissions. Votes in other decentralized protocols or apps managed by a single voter inspired the creation of collectives. These judgements have involved sensitive matters such as the application's termination. Stakeholders should ultimately have control, which is why any changes in Polkadot must be approved by public referendum, but they should also be able to elect representatives to make such decisions. Masses of relatively passive users are protected by collectives against the whims of a single, huge token holder [86].

Polkadot has two distinct governance groups: the Council and the Technical Committee [85]. These two groups can call privileged functions that influence how a proposed change is put to a referendum if they meet certain criteria. Polkadot uses origins to express privilege. In most circumstances, such as a standard balance transfer, the origin is simply the account that initiated the transaction.. But Polkadot can express different origins under certain conditions, like having two-thirds of a collective submit the same transaction, and call functions once they have attained the elevated origin.

The Council

The Council is an on-chain collective that exists to represent passive stakeholders. It does this by proposing important changes and canceling uncontroversially dangerous proposals. Any DOT (Polkadots' native currency) token holder can run for Council, but their reputation is at stake to act in good faith for the network.

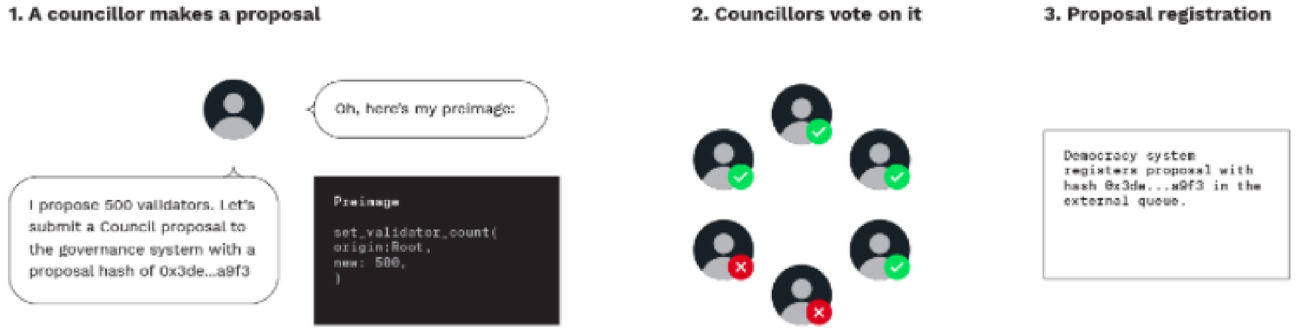

Figure 11: Demonstration of the acceptance of a proposal through a unanimous group decision amounts council members **[86]**

As seen in **Figure 11** above, a councillor can propose to send a proposal to the governance system. In this example, a councillor proposed a new validator count. If enough councillors vote to approve it, then it will eventually have a public referendum. The Council keeps its own proposal queue, separate from the public, and votes on which one should have the top priority for the next referendum. Besides normal proposals, the Council also has access to Polkadot's Treasury. The Treasury is an account that accumulates funds by inflation as well as by taking a portion of transaction fees and slashes. The Council can make and pass proposals to spend these funds for developers, community engagement, or more complex activities like using bridges and decentralized exchanges to trade its own DOTs for other tokens.

The Technical Committee

Polkadot's last line of defense against software faults is the Technical Committee. The Technical Committee, unlike the Council, is chosen by the Council based on whether or not it has supplied a formal specification or client implementation of the Polkadot protocol. The Technical Committee cannot submit suggestions, but it can expedite existing proposals so that they can be implemented in a shorter time frame than usual. If there is unanimous agreement, the Technical Committee can skip the enactment process (more on that later) and pass the proposal right away. Despite the fact that the Technical Committee is not elected, its authority is limited, and the plans that they expedite must still go through a public referendum. They can only speed up critical issue fixes through governance, but they can't control the network.

All governance choices start with a proposal and must be approved by a public vote. A proposal can be any one of a set of privileged functions that are not available to most users. Some of these are simple, like setting the balance of an account. Others set system parameters like the number of validators. The most powerful functions can change the logic of Polkadot itself. Proposals can start in three ways, namely:

- From the public, as in any DOT token holder
- From the Council, which consists of publicly elected DOT token holders
- As the result of the enactment of another proposal

Any number of public proposals can exist simultaneously, but only one can make it to a public referendum during each voting period to avoid conflicts, for example, one example given on in the Polkadot Wiki **[85]** is that if one proposal to set the validator count to 500, and another to set the validator count to 600. Users can "second" proposals that they support by locking tokens behind them, and the governance logic will select the most-supported proposal for a referendum.

Public Referenda

A core tenet of Polkadot is that a majority of stake, defined as the total number of tokens in issuance, can always command the network. Blockchains are economic vehicles that do not comprehend democratic systems of one person, one vote. Those who want to have a say in how the system develops must take an active role in it. Proposals must pass a public referendum in which all interested parties can voice their opinions. Polkadot's governance mechanism chooses the next proposal to go to referendum on its own every thirty days, alternating between awaiting Council and public suggestions to guarantee that public proposals have an equal chance of reaching referendum.

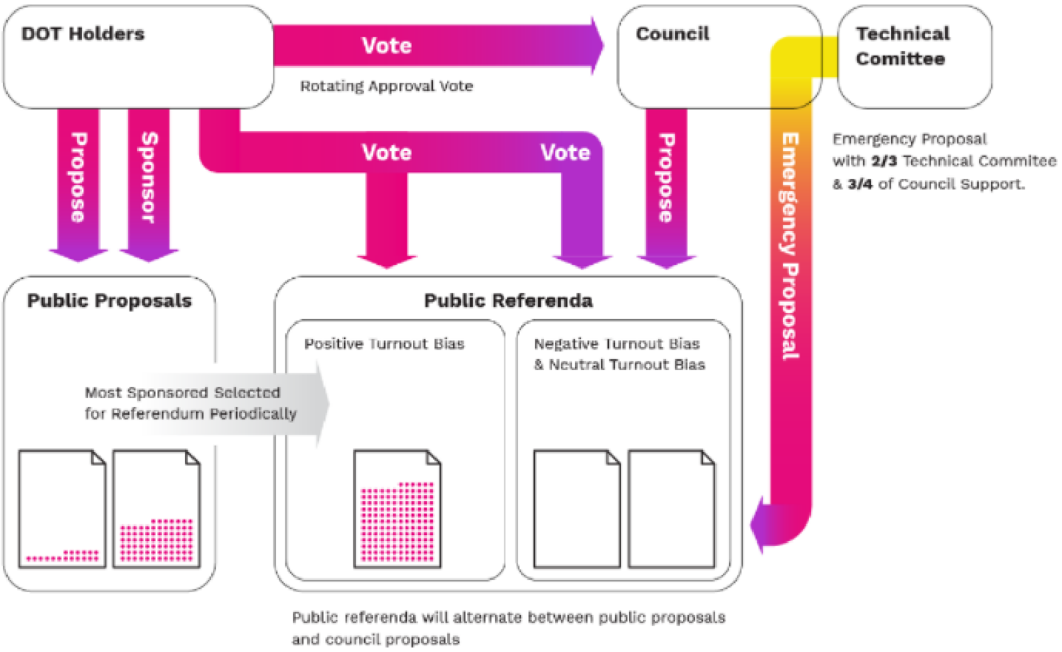

Figure 12: Flow diagram showing how both connection between the council And public's proposals and how proposals with enough votes end up as public referenda and also the technical committees fast tracking ability in the event of a major software bug

Once a referendum begins, users can begin voting. But unlike other blockchains, votes are not strictly the number of tokens in an account. Every vote comes with some conviction, some skin in the game. By default, users who voted for a passed proposal must lock tokens up until the proposal's enactment. This lock makes them stay in the network and endure the ramifications of their vote, while those on the losing side of the referendum are free to exit. But users can increase their voting power by committing to the decision for a longer period of time and thereby increasing their exposure to the outcome. Each doubling of the lock time increases the power of a user's vote, all the way up to six times the account's balance (which would be a lock of 32 enactment periods). This mechanism exists to ensure that users with little stake but strong opinions can express their conviction in referenda.

At the end of the voting period, Polkadot tallies the votes and calculates the result. If the proposal passes, then Polkadot's logic automatically schedules it for enactment, normally 30 days later to give time for external services to make any necessary adjustments and for those who oppose the decision to exit. Fast-tracked referenda, presumably for an emergency technical fix, can take effect immediately.

Adaptive Quorum Biasing

All public proposals use what is called positive adaptive quorum biasing, meaning that as the referendum turnout increases, the threshold of aye votes required to pass it lowers. Since making a protocol change comes with risk, this system was designed to favor the status quo. The outcomes of many controversial votes for example, Brexit or the U.S. elections would reverse only days later. Positive biasing ensures that only uncontroversial proposals pass. Even though referenda that use positive adaptive quorum biasing require a supermajority to pass when voter turnout is low, as turnout increases the passing threshold becomes a simple majority. This preserves the core tenet that a majority of stake can always command the network.

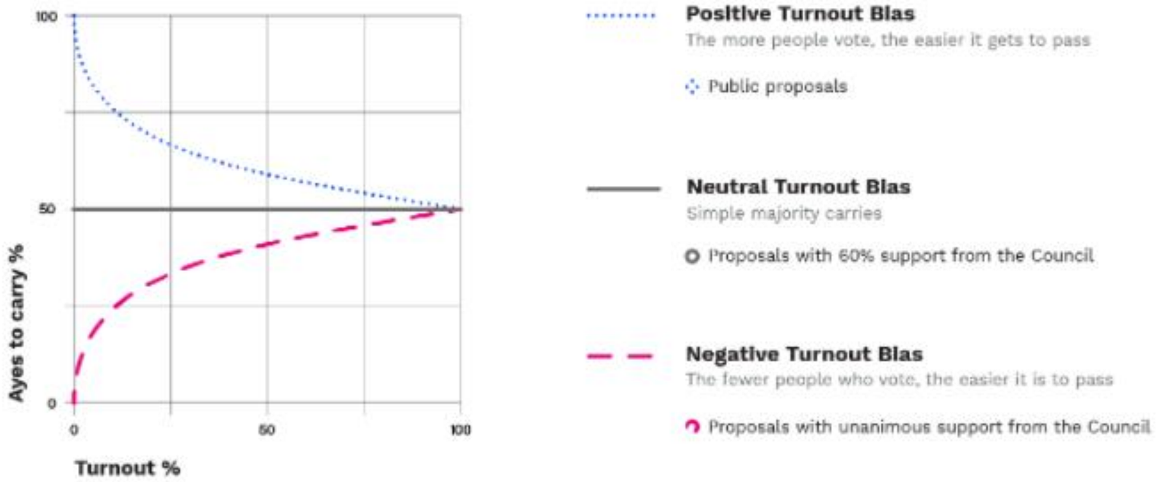

Figure 13: Adaptive Quorum biasing tunes the passing threshold according to Turnout in a referendum

Adaptive quorum biasing adjusts the passing threshold based on the referendum turnout. The higher the passing threshold for public proposals, the lower the stake turnout, favoring the status quo and preventing one large token holder from tipping a low-turnout vote. Referendums that receive full Council approval have the reverse threshold. All thresholds converge to a simple majority as turnout approaches 100%. Ordinarily, a simple majority vote is required for council initiatives. Polkadot accepts the risks of a simple majority vote to make the decision because the proposal has previously been examined by the Council. Only those referenda for which the Council has passed a unanimous vote use a negative bias. To reject the change, a supermajority of the public must vote no, although if turnout rises, this becomes a simple majority.

6.1 Bootstrapping Polkadot Governance with A Science & RTD Blockchain Platform

The Polkadot Governance model described above is incredibly decentralized and community driven and from reading the Polkadot white paper, it is quite apparent that some brilliant minds have spent years developing the model out. Using their governance model as a basis we conclude this paper with a small insight into an ambitious proposal for a science and RTD platform which adopts blockchain technology and the establishment a robust governance framework which is heavily inspired from that of Polkadot in order to construct a digital token-based crypto-economy which supports finding best possible consensus, trust and truth through adding unconventional elements known from reputation systems, betting, secondary markets and social networking **[1]**. As we have seen in Mackey and Shah's design in **section 5.2** the concept of a digital token or science coin allow support for the holder's formalized reputation as well as a means to earn rewards for carrying out tasks which are productive in the community such as carrying out quality peer review in their case. However, the concept of a digital community science coin could also be used in liquid-democracy style governance and arbitration within projects or community-driven initiatives. Our participatory research model serves as a solid basis for comprehensively leveraging collective intelligence by effectively incentivizing contributions from the crowd, such as intellectual property (IP), work, validation, assessment, infrastructure, education, assessment, governance, publication, and promotion of projects **[1]**. Decentralized Autonomous Organization (DAOs) scope a potentially effective means to be the host or root of a digital scientific community but as we mentioned in

section 3.3 more effective research still need to be conducted in order to solve some of the well-known problems around DAO's such as legality and the dilution of voting power. Given below in **figure 13** is a very high level diagram showing some of the core components needed in a robust BT inspired digital scientific community platform as required by the characteristics of an open science platform explained in **section 3.2**

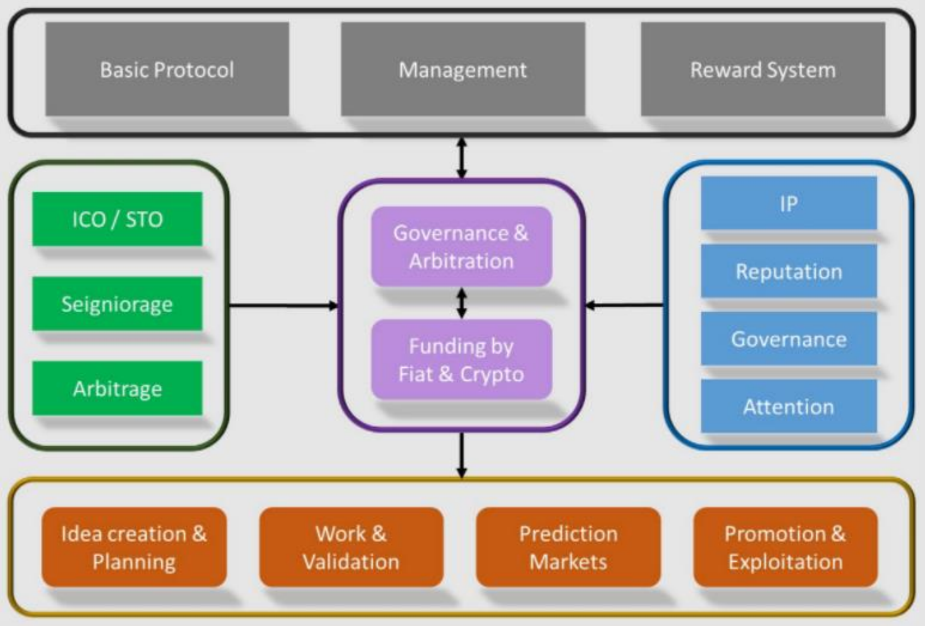

Figure 14: Organization of science & RTD by a token-based crypto-economy **[1].**

From **Figure 13** above in order to optimize quality, and to avoid manipulation and scamming, authors should stake their reputation in a proof of stake-esque base system as proposed by Ethereum 2.0 **[8]**. Upon approval, the blocks are appended to the "ledger of knowledge" that is archived in various forms, be it as publicly in journal publications or patents, or in internal documents stored on institutional or corporate databases. In absence of immediate consensus, and analogously to forks in blockchain, various theories transiently compete until sufficient evidence has been aggregated to convince a critical mass of the community. Many proofs of stake chains require a validator consensus of at least two thirds which is known as a super majority agreement in order for information to be deemed valid and get pushed to the actual blockchain. However, in a scientific context 66% consensus would not be sufficient enough and modifications to the minimum threshold of consensus may have to be altered to ensure the quality of scientific information. However, having identified these analogies to protocols in blockchain, we notice that involvement of the scientific community is highly relevant to reviewing, but contributions of the crowd at large to the creation of initial intellectual property (IP), validation and dissemination are rather poorly incentivized and acknowledged.**[1]** A blockchain-based token economy has the potential to highly encourage a collaborative approach for the mutual benefit of contributors and the objectives of the project.

Blockchain technologies can uniquely implement transparent rule sets on its tamper-free and immutable ledger to incentivize, credit and reward a broad repertoire of community contributions. We begin by demonstrating the advantages that a token economy may provide for research and R&D initiatives. Evidently, seigniorage, ICOs, and dynamically developing crowdfunding may feed financial resources into a project at various phases of development. These assets may be utilized to directly recruit, crowdsource, and encourage workforce, idea generation, expertise contributions, management, and other services. Tokens are rewarded or destroyed in reputation systems based on the greatest connection between forecasts and target outcomes. Skin in the game techniques can successfully "dilute" corrupted assessment, for example, by malevolent individuals establishing a large number of pseudonymous identities and utilizing them to obtain disproportionately huge impact. Mechanisms for dealing with such hostile assaults. Proof of identification (POI) **[88],** for example, has been suggested as shown in this work **[89].** Reputation tokens can mirror track record, for example, obtained for quality and speed of project work, validation, advise, education, team building, promotion and leadership, to substantiate the overall credibility of contributors. In contrast with the current state where even the number of citations of a particular paper or author is usually only available under subscription models, blockchain implementation would offer rendering such records publicly available.

Without going into too much detail here (as this is what our next paper scopes) we can se that the ambitious use of BT to not only control or govern sub sectors in academia such as peer- review or open access in isolated environment, but rather to encapsulate the characteristics of BT to develop a completely digital token based crypto economy which facilitates all facets of the current scientific industry. The end game here is to increase transparency efficiency and incentivisation in science in order to maximizes the quality of scientific endeavours.

Conclusion

In this study we analysed how blockchain technology can promote open science. We provided an intricate review of state-of-the-art blockchain inspired projects that currently exist in this space, to evaluate related research potentials and obstacles for this subject. We established the prerequisites for an open scientific environment and compared them to the attributes of BT to see if they were compatible. As a result, we were able to answer our initial research question and establish the technology as a dependable and adequate platform for open science. Nonetheless, we see BT as just one of many building blocks, and we feel that the concepts underpinning open science can only be realized if all of the elements are placed together in a meaningful way and complement each other. We then highlighted some of the most prevalent shortcomings within the current academic infrastructure such as the problems in t peer-review aswell as the needless existence of scientific publication paywall just to mention a few. We collected and reviewed topic related literature and blockchain projects to describe the current situation. We illustrated the possibilities of the technology by many practical examples to show its capabilities for scientific workflows. Some of the analysed projects already offer functionalities that can optimize research processes such as the introduction of a reputation system in Dhillon's design or the integration of a crypto science token to incentivise the community to act in good faith as proposed in Mackey and Shah's design, but as we pointed out in **section 5.3** most of them need additional development time to implement their aimed features. The combination of well-known characteristics like hashing, decentralization, and immutability makes the BT unique and explains the increasing interest of science and industry in it. Because of the scarcity of literature, unanswered problems, and the number of initiatives in idea or prototype stages, it is important to recognize that the use of blockchains in the context of open research is still in its early stages. Nonetheless, the technology may already make substantial contributions in a variety of areas, such as enhancing researchers' present workflows, developing confidence in technological systems, allowing new partnerships, and minimizing existing challenges. However, considerable work has to be done in terms of standards, governance models, user friendliness, interfaces, security and legal challenges, and instructional efforts to fully realize the technology's promise. We expect the BT to become more mature over time as its adoption expands. In this sense, overcoming the mentioned difficulties will be critical in the future. Altogether, after our review, we summarize that the capabilities of the BT for open science are by far not exhausted yet. We conclude that the technology can have a positive impact on scientific work and its open ecosystems but that primarily depends on the scientific community's and all other connected stakeholders' approval of the technology, which is currently uncertain. However, on that note we should conclude with the final realisation that the a simple shift in direction in regard to the way processes are enacted or implemented in academia such as through the implementation of an emerging technology such as BT or any other, could not possibly boast the claim to solve everything. So much more needs to be done but we do want to highlight that blockchain technology "could" possibly act as a cog in the entire system to help realise the vision and ethos of science

Appendix

1. **Colored Coins:** The term "Colored Coins" loosely describes a class of methods for representing and managing real world assets on top of the Bitcoin Blockchain through the attachment of transactional metadata which can be tracked and referenced.

2. **Tokenomics**: Tokenomics is the topic of understanding the supply and demand characteristics of cryptocurrency

3. **Prediction Markets:** The prediction market is a market where people can trade contracts that pay based on the outcomes of unknown future events. The market prices generated from these contracts can be understood as a kind of collective prediction among market participants. These prices are based on the individual expectations and willingness of investors to put their money on the line for those expectations.

4. **Arbitrage**: With foreign exchange investments, the strategy known as arbitrage lets traders lock in gains by simultaneously purchasing and selling an identical security, commodity, or currency, across two different markets. This move lets traders capitalize on the differing prices for the same said asset across the two disparate regions represented on either side of the trade.

5. **3rd Gen Blockchain:** Third-gen blockchains aim to resolve fundamental flaws including scalability and interoperability which means blockchain can sustain mass adoption and not suffer problems like slow transaction time and closed systems

6. **The double spending problem:** The double spending problem is a phenomenon in which a single unit of currency is spent simultaneously more than once. This creates a disparity between the spending record and the amount of that currency available.

7. **51% attack:** A 51% attack refers to an attack on a blockchain—most commonly Bitcoin, for which such an attack is still hypothetical—by a group of miners controlling more than 50% of the network's mining hash rate or computing power.

8. **Inter Planetary File System (IPFS):** IPFS is a peer-to-peer (p2p) storage network. Content is accessible through peers located anywhere in the world, that might relay information, store it, or do both. IPFS knows how to find what you ask for using its content address rather than its location.

9. **Permissioned blockchain:** Permissionless blockchains are blockchains that require no permission to join and interact with. They are also known as public blockchains. Most of the time, permissionless blockchain is ideal for running and managing digital currencies.

10. **Permissionless blockchain:** Permissionless blockchains are blockchains that require no permission to join and interact with. They are also known as public blockchains. Most of the time, permissionless blockchain is ideal for running and managing digital currencies.

11. **The Byzantine Fault Tolerance Problem:** the "Byzantine Generals Problem", developed to describe a situation in which, in order to avoid catastrophic failure of the system, the system's actors must agree on a concerted strategy, but some of these actors are unreliable.

12. **Side Chains:** A sidechain is a side blockchain that is linked to another blockchain, referred to as the main chain, via a two-way peg. They are usually used to store data off-chain that would otherwise be too costly to store on the main blockchain.

13. **Web3.**js: web3.js is a collection of libraries that allow you to interact with a local or remote Ethereum node using HTTP, IPC or WebSocket. ... js as well as providing an API reference documentation with examples

14. **Genesis Block:** A Genesis Block is the name given to the first block a cryptocurrency, such as Bitcoin, ever mined

15. **Coin Voting:** Coin voting in blockchain is a way for community members to have a say in the decisions that are made in a blockchain protocol. They must have skin-in-the-game to have a say in votes. The more coins or stake someone has the greater their voting power

16. **Forking:** Blockchain forks are essentially a split in the blockchain network. The network is built on an open source software, and the code is freely available. Forks occur when the software of different miners disagree over the best way forward for blockchain. It's up to miners to decide which blockchain to continue using. This disagreement causers miners to work the now two different forks the original blockchain before and the new one with changed protocols after it

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