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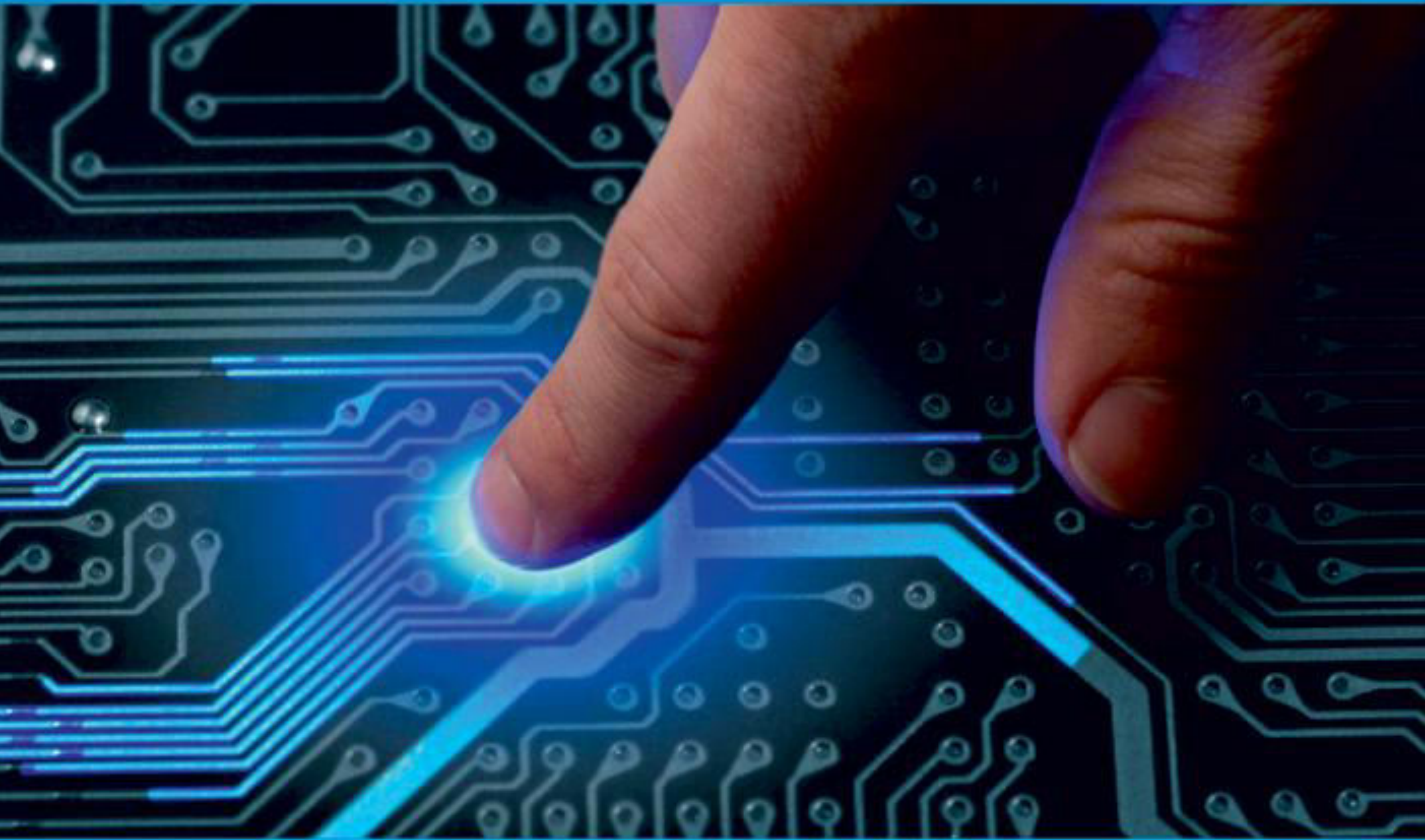

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Blockchain Technology and Blockchain Projects Fostering Open Science

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ABSRACT: Blockchain is considered by many to be a disruptive core technology. Although many researchers have realized the importance of blockchain, the research of blockchain is still in its infancy. Consequently, this study reviews the current academic research on blockchain, especially in the subject area of business and economics. Based on a systematic review of the literature retrieved from the Web of Science service, we explore the top-cited articles, most productive countries, and most common keywords. Additionally, we conduct a clustering analysis and identify the following five research themes: "economic benefit," "blockchain technology," "initial coin offerings," "fintech revolution," and "sharing economy." Recommendations on future research directions and practical applications are also provided in this paper.

KEYWORDS: Blockchain, Classification, Applications.

I. INTRODUCTION

The concepts of bitcoin and blockchain were first proposed in 2008 by someone using the pseudonym Satoshi Nakamoto, who described how cryptology and an open distributed ledger can be combined into a digital currency application (Nakamoto 2008). At first, the extremely high volatility of bitcoin and the attitudes of many countries toward its complexity restrained its development somewhat, but the advantages of blockchain—which is bitcoin's underlying technologyattracted increasing attention. Some of the advantages of blockchain include its distributed ledger, decentralization, information transparency, tamper-proof construction, and openness. The evolution of blockchain has been a progressive process. Blockchain is currently delimited to Blockchain 1.0, 2.0, and 3.0, based on their applications. We provide more details on the three generations of blockchain in the Appendix. The application of blockchain technology has extended from digital currency and into finance, and it has even gradually extended into health care, supply chain management, market monitoring, smart energy, and copyright protection.

This study will conduct a systematic and objective review that is based on data statistics and analysis. We first describe the overall number and discipline distribution of blockchain-related papers. A total of 756 journal articles were retrieved. Subsequently, we refined the subject area to business and economics, and were able to add 119 articles to our further analysis. We then explored the influential countries, journals, articles, and most common keywords. On the basis of a scientific literature analysis tool, we were able to identify five research themes on blockchain. We believe that this data-driven literature review will be able to more objectively present the status of this research.

II. OVERVIEW

In principle, a blockchain should be considered as a distributed append-only timestamped data structure. Blockchains allow us to have a distributed peer-to-peer network where non-trusting members can verifiably interact with each without the need for a trusted authority. To achieve this one can, consider blockchain as a set of interconnected mechanisms which provide specific features to the infrastructure, as illustrated in Fig. 1. At the lowest level of this infrastructure, we have the signed transactions between peers. These transactions denote an agreement between two participants, which may involve the transfer of physical or digital assets, the completion of a task, etc. At least one participant signs this transaction, and it is disseminated to its neighbours. Typically, any entity which connects to the blockchain is called a *node*. However, nodes that verify all the blockchain rules are called full nodes. These nodes group the transactions into *blocks* and they are responsible to determine whether the transactions are valid, and should be kept in the blockchain, and which are not.

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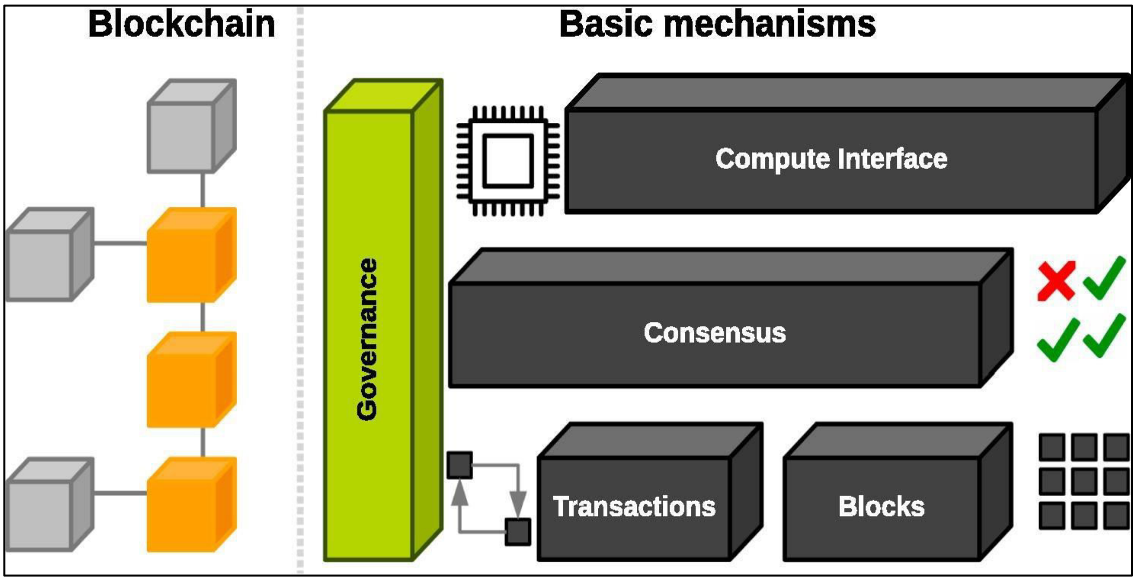

Fig. 1. An overview of blockchain architecture.

A valid transaction means, for instance, that Bob received one bitcoin from Alice. However, Alice may have tried to transfer the same bitcoin, as it is a digital asset, to Carol. Therefore, nodes must reach to an agreement on which transactions must be kept in the blockchain to guarantee that there will be no corrupt branches and divergences. This is actually the goal of the second Consensus layer. Depending on the blockchain type, different Consensus mechanisms exist. The most well-known is the *Proof-of-work (PoW)*. PoW requires solving a complicated computational process, like finding hashes with specific patterns, e.g. a leading number of zeroes, to ensure authentication and verifiability. Instead of splitting blocks across proportionally to the relative hash rates of miners (i.e., their mining power), *Proof-of-Stake (PoS)* protocols split stake blocks proportionally to the current wealth of miners (Pilkington, 2016). This way, the selection is fairer and prevents the wealthiest participant from dominating the network. Many blockchains, such as Ethereum , are gradually shifting to PoS due to the significant decrease in power consumption and improved scalability.

Current literature categorises blockchain networks in several ways. These categories are formed according to the network's management and permissions as *public*, *private* and *federated*. In public blockchains anyone can join as a new user or node miner. Moreover, all participants can perform operations such as transactions or contracts. In private blockchains; which along with the federated belong to the *permissioned* blockchain category, usually, a whitelist of allowed users is defined with particular characteristics and permissions over the network operations. Since the risk of Sybil attacks is almost negligible there, private blockchain networks can avoid expensive PoW mechanisms. Instead, a wider range of consensus protocols based on disincentives could be adopted. A federated blockchain is a hybrid combination of public and private blockchains. Although it shares similar scalability and privacy protection level with private blockchain, their main difference is that a set of nodes, named *leader* nodes, is selected instead of a single entity to verify the transaction processes. This enables a partially decentralised design where leader nodes can grant permissions to other users. In this article, we provide a more fine-grained blockchain network classification than current the state-of-the-art because, in addition to classical features such as the ownership and management of the information shared in the blockchain, we consider features such as transaction approval time, or security aspects such as anonymity. Table 1 summarises the main characteristics of each blockchain network regarding efficiency, security and consensus mechanisms.

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Property	Public	Private	Federated
Consensus	Costly PoW	Light PoW	Light PoW
Mechanism	All miners	Centralised Organisation	Leader Node set
Identity	(Pseudo) Anonymous	Identified users	Identified users
Anonymity	Malicious	Trusted	Trusted
Protocol Efficiency	Low efficiency	High efficiency	High efficiency
Consumption	High Energy	Low Energy	Low Energy

Table 1. Classification and main characteristics of blockchain networks.

III. LITERATURE

Since it is an early research phase, there is little literature about open science in combination with BT, but still, there are exciting and promising concepts, ideas, discussions, and approaches that we want to describe and highlight.

Dhillon wrote an article and with others a book section about BT and open science. They start the relevant chapter in their book with the current reproducibility crisis and the rare publications of negative results. Dhillon et al. state 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 while protecting critical data of patients (Dhillon et al., 2017). Also, other publications are proposing the use of BT in the medical or biological area to provide, among other aspects, transparency and trust. Further to the research process, Dhillon also proposes to apply their approach to implement a kind of reputation system (with an API) as a reward for researchers and an indicator for the quality of contributions.

Another use case highlighted by Dhillon et al. is blockchain-based prediction markets, where mainly experts try to predict a specific outcome like the potential of reproducibility of an experiment. To create an incentive to participate, users get rewarded for the right prediction, for instance, by monetary coins/tokens of the related blockchain. An article by Extance (2017) contains similar statements saying that the BT can enhance the current replication situation in science, but he additionally mentions the potential of the technology for the peer-review process to build up trust due to immutability and transparency. But also, the article reiterates the statement made by Pagliari (Extance, 2017) who expresses concerns about storing possibly incorrect data in a blockchain that are then immutable. A patent about the usage of BT in open scientific research (Ahn et al., 2018) complies with the open principles and focuses on the integration of the technology into research workflows to allow such a tamper-proof sharing of information to improve the trustworthiness in science.

Projects: - In the following sections, we describe use cases of the six categories we defined along with associated projects. We do not aim to present every single project in detail as it would be far beyond the scope of this paper; moreover, several of them are similar and follow more or less the same goals. Also, we include some approaches and applications that are not focused on science but contain specific interesting functions or mechanisms that are promising if transferred to blockchain-based research workflows.

Social Research Platform / Repository: - We classified most of the projects that we analysed as social research platforms/repositories. Especially in this category, the concepts and applications often provide many overlapping functionalities and have similar goals. Potential use cases are to create open platforms, repositories, or marketplaces to support collaborations in science and to allow open access to research data hence improving the reproducibility of experiments, studies, and other kinds of research. Typically, they contain much more capabilities like communication methods, reputation and identity mechanisms, and incentive systems for their users. Further, the traceability of the BT serves as protection of the contributors and creates a trustworthy and transparent environment.

IV. RESEARCH POTENTIALS

In this section, we describe in the context of our third research question challenges and research potentials that we identified during our analysis. Future works should address them in order to eliminate technological and legal insecurities and to enhance the usability of the BT for open science and beyond. We focused on some of the most relevant and promising topics in our view, which got not or insufficiently investigated yet. They shall provide an

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impulse in the form of starting points for further research; as a positive side effect, addressing these issues can partially also foster other non-scientific areas.

We want to point out that the challenges presented in this section are very complex and profound, so we do not expect them to get resolved in the near future. For example, the correctness problem of software which is fundamental to smart contracts (see section 6.1) is around since the early days of programming, and till today a solution is not yet in sight. Therefore, the following topics are an outlook into vital pillars that need to be considered in the course of a broad integration of BT.

V. CONCLUSION

This paper contains an analysis about how the BT can foster open science, a review of the state-of-the-art, and an evaluation of relevant research potentials and challenges for that subject. We identified the requirements for an open scientific ecosystem and compared them with the properties of BT to verify whether they fit together. In that way, we answered our first research question and determined the technology as a reliable and appropriate infrastructure for open science. Nevertheless, we regard BT as just one building block among others and we believe that the ideas behind open science can only be implemented if all pieces are put together in a meaningful way and complement each other. Concerning our second research question, 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, but most of them need additional development time to implement their aimed features. For our third research question, we identified several existing challenges and research potentials. With this, we intend to draw attention to various promising and essential research topics that should get addressed to support the further development of the BT for open science.

Our study has recognized some limitations. First, this paper only analyses the literature in Web of Science Core Collection databases (WOS), which may lead to the incompleteness of the relevant literature. Second, we filter our literature base on the subject category in WOS. In this process, we may have omitted some relevant research. Third, our recommendations have subjective limitations. We hope to initiate more research and discussions to address these points in the future.

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