Blockchain: Research and Applications 1 (2020) 100005

Contents lists available at ScienceDirect

Blockchain: Research and Applications

journal homepage: www.journals.elsevier.com/blockchain-research-and-applications

Research – A blockchain of knowledge?

Jens Ducrée

School of Physical Sciences, Dublin City University, Ireland

ARTICLE INFO

Keywords:
Blockchain for research
Reputation systems
Consensus
Prediction markets
Tokenization
Blockchain-enabled staking
Incentivization

ABSTRACT

This perspective proposes that, by virtue of its sophisticated trust and consensus finding mechanisms, blockchain has the clear potential to substantially upgrade the processes and organization traditionally underpinning academic science and commercial technology development comprising funding, project delivery, generation of intellectual property, documentation and publication. For supporting this hypothesis, striking analogies between the concepts underlying blockchain technology with research are identified, and applied to the generation of verified knowledge in science and technology development. It is then elaborated how a blockchain enabled token economy can efficiently and transparently incentivize and coordinate an integrative and community-inclusive participatory approach to fuel crowdsourcing of collective intelligence for contributing ideas, work, infrastructure, funding, data, validation, management, assessment, governance, arbitration and exploitation of projects. Quality, credibility and direction of projects are optimized by demanding collateral "skin-in-the-game" from contributors based on blockchain-enabled staking, reputation systems and prediction markets. This way research progress emerges as a chain of community generated and independently vetted blocks of scientific knowledge; these new blocks are concatenated with the state-of-the-art according to transparent consensus mechanisms.

The distributed ledger technology (DLT) blockchain has massively evolved from its origin as the pure digital currency Bitcoin in 2008/2009 [1] into multiple applications spaces. The term "blockchain" roots in bundling of cryptocurrency transactions into data blocks that contain a unique, convoluted trace ("hash"/"Merkle tree") of their predecessors. Following a well-defined consensus protocol, one particular block is selected, time-stamped and amended to an immutable and unforgetable distributed ledger file that is replicated on copious independent nodes. In the absence of intermediaries, trust within this peer-to-peer network is secured by a combination of decentralized computing, storage and transaction fees. The sophisticated interplay of these mechanisms protects, at utmost likelihood, against nefarious spamming ("Denial of Service") attacks, false identity ("Sybil") generation and hostile takeover attempts ("Byzantine Fault Tolerance").

Contributions from the "crowd" for sustaining the blockchain are cryptoeconomically incentivized, e.g., for "mining" by solving computationally very demanding cryptographic puzzles ("hash rate" in "Proof-of-Work"), as, for instance, in Bitcoin [1], or by vouching (crypto-)assets ("Proof-of-Stake") as, for instance, in the recently launched Ethereum 2.0 upgrade ("Eth2" [2]), and as it will be most relevant in the present context. These cryptoassets can be converted into fiat money at secondary exchanges, spent on utility charges, staked for supporting credibility or for conferring voting rights in, for instance, liquid-democracy style governance.

Initially enabled on the Ethereum blockchain [3], transactions can be coupled to code that is securely stored on the decentralized ledger and executed on its decentralized virtual machine ("EVM"). These "smart contracts" can accept input, e.g., stock values or weather data, from credible on- or properly staked off-chain sources ("oracles" [4–6]) to trigger conditionals. Wrapped into convenient browser interfaces, such programmable money evolves into decentralized applications ("DApps") that have already demonstrated several compelling use cases, e.g., for decentralized finance ("DeFi" [7]), supply chain management [8–13], asset and provenance tracking [14], e.g., for physical and digital collectibles [15] or food [16]. Another notable, cryptoeconomically enabled feature of blockchain are "non-fungible tokens" (NFTs [17,18]), which represent a digital certificate of (possibly partial) ownership representing a unique real-world asset such as property [19], commodities [20] or

E-mail address: jens.ducree@dcu.ie.

Production and Hosting by Elsevier on behalf of KeAi

https://doi.org/10.1016/j.bcra.2020.100005
Received 23 September 2020; Received in revised form 10 December 2020; Accepted 12 December 2020

artwork [21,22]. Blockchain can also implement self-sovereign identity ("SSI") systems [23,24], e.g., to properly attribute credentials in research and education without intermediary agencies.

While its origins are found in cryptography, finance and computer science, the breath taking advancement of blockchain technology over the past decade has emerged from often unprecedented linkages with a wide scope of other fields, such as economics, game theory, banking, risk management, data science, data security, identity management, logistics, supply chains, trading, education, law, administration, governance, political science, psychology, ethics, arts and social sciences. This exceptional interdisciplinarity of blockchain technology has proven to be a major engine of innovation. In order to sharpen focus while not losing for diverse, non-expert audiences, Table 1 in the Appendix lists common blockchain jargon with links to explanatory external references.

This perspective concisely pinpoints striking parallels between the processes in scientific discovery and blockchain. This disruptive DLT has so far mainly materialized as "storage of value", such as Bitcoin often touted as "digital gold" [25], or for developing "Global Commons" [26], i.e., widely shared, community-spirited objectives such as the development of transnational blockchain ecosystems. The following will reveal manifold opportunity for significantly upgrading the way science has been organized over the last centuries by novel tools that already drive the rapid growth of the modern cryptoeconomy.

From a conceptual level, especially fundamental research pursues scientific Commons through an open competition between autonomous players. Staking their professional reputation, researchers publish new intellectual property ("IP") and data sets. These artefacts are firmly anchored in broadly accepted protocols, e.g., for data acquisition, analysis, interpretation, validation and documentation, and tightly interweaved with prior art through citations.

Operating without central authority, trust and consensus on the significance, credibility and reproducibility of the scientific discovery is endowed by independent peers before these "blocks" of information are amended to the perpetual public library of knowledge. In addition to the authors, the target journal including its publishing house, editors and referees put their (financially valuable) reputation on the line for endorsing the quality and integrity of the reported findings. However, despite of established rankings for universities [27] or scientists [28], the underlying metrics [28] and conversion schemes for reputation in academia, e.g., for decisions on funding, promotions, prestigious awards, high-exposure presentation slots and prestigious appointments to boards or committees, remain somewhat inconsistent and obscure [29]. Notably, a trading platform is missing for researchers, reviewers, the scientific community and the crowd at large; in such secondary markets, contributors could stake their skin-in-the game (and thus potentially benefit) along the entire lifespan of an initiative extending between prognosis on early-stage ideas, funding, validation/reproducibility of results and assessment of progress.

In many aspects, the blockchain-enabled token economy ("tokenization") offers great potential for boosting paramount community involvement to improve the quality, raise the credibility and widen the adoption and impact of research outputs [30–32]: New IP and data can be time-stamped and indisputably filed as NFTs on the blockchain as proof-of-knowledge for firmly claiming (co-)author-, inventor- and ownership, possible backed by blockchain-based (self-sovereign) identity management. To avoid potential conflict with present employment regulation and tax status, academic research could initially focus on blockchain-tracked reputation systems, instead of potentially conflict-laden pecuniary rewards by cryptoassets, which would then largely map the current framework.

In a scientific "betting game", these reputation tokens can be staked as collateral to support the credibility of proposals, deliverables, evaluation and forecasts. As already commonplace in the blockchain community, token bounties [33,34] could be publically advertised for flagging issues, e.g., related to the notorious reproducibility/replication crisis in science [35–39], or for elaborating refinements and thus promoting community participation beyond the core team and project duration. Furthermore, attention tokens [40] can be issued to users in the crowd for completing tutorials, adopting outcomes and spreading the news of the research initiative.

Interestingly, it has been convincingly shown that such crowdsourcing of collective intelligence [41], which can be efficiently orchestrated by the token economy, can solidly back prediction markets to guide project resources, paper review and reward schemes. The reliability of forecasts may be further invigorated by "curation markets" [42], e.g., in combination with automated market makers (AMMs), such as liquidity guaranteeing "token bonding curves" (TBCs) [43]. In addition to classical funding mechanisms such as public sponsorship, equity and loans, blockchain provides the powerful cryptoeconomical instruments of seigniorage ("minting"), i.e., issuing a project-specific cryptocurrency through initial coin/token/security offerings (ICOs/ITOs/ISOs), and possible arbitrage gains in its secondary markets, e.g., TBCs, and crowdfunding. The core elements of the proposed "blockchain of knowledge" are schematized in Fig. 1.

Particularly in view of nearly ubiquitous availability of 21st century technologies like cloud computing, artificial intelligence (AI), additive manufacturing like 3D printing, virtualization by digital twins, open-access lab and "science as a service" facilities [44], literally anyone with a great idea, relevant expertise, skills or equipment, whether affiliated with a prestigious institution or an independent "citizen scientist", can contribute to and benefit from the token economy. Such community-inclusive, participatory models would be considerably boosted by releasing standards for materials, components and methods, as proposed in various fields [45,46]. Science discovery could thus reach out far beyond its present silo into a truly global resource of brains, skills, work force and infrastructure.

Finally, the novel concept of Decentralized Autonomous Organizations ("DAOs") has been developed to even stage sizeable projects by loosely organised, borderless and crowd funded grassroots initiatives; in the context of science, future DAOs could literally "live" the ideal of autonomous academic self-administration; this way an inclusive community conceives, plans, selects, manages, governs, publishes and exploits projects with guidance from skin-in-the-game staked "liquid democracy" style governance as well as from intelligence delivered by secondary validation and prediction markets.

Developers have already targeted various well-known challenges of blockchain technologies, e.g., regarding scalability, transaction speed and fees, data storage and access, privacy, identity, cross-platform interoperability, standardization, governance, arbitration, auditing and identity management. Power consumption and confidentiality have been successfully addressed by federated, Proof of Stake or also Proof of Authority fortified blockchains where nodes are exclusively run by closed consortia of widely trusted, e.g., academic institutions [47]. Many blockchain projects have also intensively liaised with state bodies and the corporate sector to solve mission critical compliance with work flows, regulation and legislative frameworks [48].

Nevertheless, after only a decade of development, and quite similar to the world wide web back in the 1990s, the maturity of many components in the blockchain stack may still be labelled "work in progress"; importantly, critical legal and regulatory issues still need to be solved. Also convenient, barrier-free and universal access still needs to be considerably advanced to foster prolific adoption by non-experts; this is a crucial prerequisite for tapping into vital economy of scale effects, and to leverage the compelling benefits of blockchain for its various application spaces. Note that first use cases at the very promising cross roads of science with blockchain have been reported in the recent past [26,32,47,49–53].

In summary, this perspective mapped key processes and organisational aspects at the backbone of fundamental science and technology development to their equivalents in the very rapidly emerging blockchain technology. It has been shown that a blockchain-enabled token economy, its secondary markets and transparent incentivization, staking

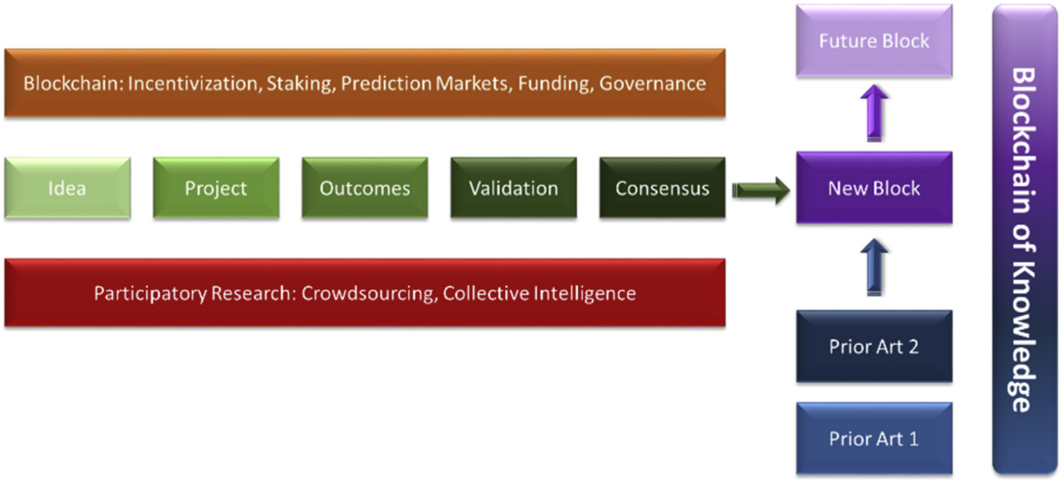

Fig. 1. Blockchain of Knowledge. Blockchains incentivize positive behaviour in a participatory research model where a team and the crowd provide intellectual contributions, work force and infrastructure, expert predictions, funding and governance. Smart contracts coordinate all stages of knowledge creation from idea and project work, validation of its outcomes; they support finding consensus according to widely accepted methodologies before new "blocks" of knowledge can be added to a common, immutable and time-stamped public ledger documenting the related prior art. While, for the sake of clarity, the schematic portrays a linear chain, the structure of scientific knowledge would be best captured by a multi-branched and highly interlinked network reflecting its various disciplines and their cross-fertilization.

and reputation systems can efficiently source the collective intelligence in a participatory model to markedly enhance quality, efficiency, reproducibility, credibility, transparency, inclusiveness and impact of research outcomes. On the analogy of the game-changing "Web 3.0" technology[1] blockchain, the creation of valuable scientific knowledge can thus be substantially enhanced by establishing a decentralized ledger of prior art; this publically readable file is successively extended by community-sanctioned blocks of research outcomes that are generated and independently verified by a properly incentivized, participatory approach.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Appendix. Terminology

Table 1
Common terms in blockchain technology and its highly multidisciplinary environment with links to explanatory references [54] in alphabetical order.

Term	Link to Explanatory Reference
Blockchain	https://en.wikipedia.org/wiki/Blockchain
Byzantine Fault	https://en.wikipedia.org/wiki/Byzantine_fault
Collective Intelligence	https://en.wikipedia.org/wiki/Collective_intelligence
Commons	https://en.wikipedia.org/wiki/Global_commons
Consensus	https://en.wikipedia.org/wiki/Consensus_(computer_science)
Cryptocurrency	https://en.wikipedia.org/wiki/Cryptocurrency
Decentralized Autonomous Organization (DAO)	https://en.wikipedia.org/wiki/Decentralized_autonomous_organization
Decentralized Application (DApp)	https://en.wikipedia.org/wiki/Decentralized_application
Denial-of-service (DoS)	https://en.wikipedia.org/wiki/Denial-of-service_attack
Distributed Ledger (Technology, DLT)	https://en.wikipedia.org/wiki/Distributed_ledger
Fiat Money	https://en.wikipedia.org/wiki/Fiat_money
Hash	https://en.wikipedia.org/wiki/Hash_function
Initial Coin Offering (ICO)	https://en.wikipedia.org/wiki/Initial_coin_offering
Intellectual Property (IP)	https://en.wikipedia.org/wiki/Intellectual_property
Liquid democracy	https://en.wikipedia.org/wiki/Liquid_democracy
Merkle Tree	https://en.wikipedia.org/wiki/Merkle_tree
Peer-to-Peer (P2P)	https://en.wikipedia.org/wiki/Peer-to-peer
Proof of Stake (PoS)	https://en.wikipedia.org/wiki/Proof_of_stake
Proof of Work (PoW)	https://en.wikipedia.org/wiki/Proof_of_work
Replication crisis	https://en.wikipedia.org/wiki/Replication_crisis
Reputation System	https://en.wikipedia.org/wiki/Reputation_system
Seigniorage	https://en.wikipedia.org/wiki/Seigniorage

(*continued on next column*)

[1] Note that the definition of the terms "Web3" or "Web 3.0" technology differs, depending on the application context.

Table 1 (*continued*)

Term	Link to Explanatory Reference
Self-Sovereign Identity (SSI)	https://en.wikipedia.org/wiki/Self-sovereign_identity
Smart Contract	https://en.wikipedia.org/wiki/Smart_contract
Sybil Attack	https://en.wikipedia.org/wiki/Sybil_attack
Wisdom of the Crowd	https://en.wikipedia.org/wiki/Wisdom_of_the_crowd

References

[1] S. Nakamoto, Bitcoin: a peer-to-peer electronic cash system, Published: 24/05/2009; Accessed: 15/09/2020; Available on, https://bitcoin.org/bitcoin.pdf, 2009.
[2] Ethereum 2.0 ("Eth2"), Accessed: 02/12/2020; Available on, https://ethereum.org/en/eth2/.
[3] V. Buterin, White paper· ethereum/wiki wiki · GitHub, Accessed: 24/07/2020; Available on, https://github.com/ethereum/wiki/wiki/White-Paper, 2014.
[4] Band protocol - Secure, Scalable blockchain-agnostic decentralized oracle, Accessed: 17/08/2020; Available on, https://bandprotocol.com/.
[5] Blockchain oracles, Accessed: 24/07/2020; Available on, https://blockchainhub.net/blockchain-oracles/.
[6] Oracles, Accessed: 10/08/2020; Available on, https://docs.corda.net/docs/corda-os/4.5/key- concepts-oracles.html.
[7] S. Austin, Understanding the landscape of decentralized finance, Published: 20/09/2020; Accessed: 22/09/2020; Available on, https://cointelegraph.com/news/understanding-the- landscape-of-decentralized-finance.
[8] J. Ducrée, M. Gravitt, R. Walshe, S. Bartling, M. Etzrodt, T. Harrington, Open platform concept for blockchain-enabled crowdsourcing of technology development and supply chains, Front. Blockchain 3 (2020) 386525, https://doi.org/10.3389/fbloc.2020.586525.
[9] J. Birch, Blockchain and 3D Printing Are Reinventing Aerospace Supply Chains, 2019.
[10] R. Wolfson, Book review on don tapscott's collaborative 'supply chain revolution', Published: 25/08/2020; Accessed: 26/08/2020; Available on, https://cointelegraph.com/news/book-review-of-don-tapscott-s-collaborative-supply-chain-revolution.
[11] K. Francisco, D. Swanson, The supply chain has No clothes: technology adoption of blockchain for supply chain transparency, Logistics 2 (2018), https://doi.org/10.3390/logistics2010002.
[12] B. Dimitrov, How walmart and others are riding A blockchain wave to supply chain paradise, Accessed: 24/07/2020; Available on, https://www.forbes.com/sites/biserdimitrov/2019/12/05/how-walmart-and-others-are- riding-a-blockchain-wave-to-supply-chain-paradise/, 2019.
[13] F. Betti, J. Ni, How China can rebuild global supply chain resilience after COVID-19, Available on, https://www.weforum.org/agenda/2020/03/coronavirus-and-global-supply- chains/, 2020.
[14] Everledger - blockchain asset tracking, Accessed: 10/11/2020; Available on, https://www.everledger.io/blockchain-asset-tracking/.
[15] Cryptokitties, Accessed: 24/07/2020; Available on, https://www.cryptokitties.co/.
[16] Blockchain Use Cases, How blockchain will transform the food supply chain - from harvest to market, increasing visibility for all, Published: 29/04/2020; Accessed: 02/12/2020; Available on, https://dzone.com/articles/how-blockchain-will-transform-the-food-supply- chai.
[17] M. Kramer, What are non-fungible tokens? (NFTs), Available on, https://decrypt.co/resources/non-fungible-tokens-nfts-explained-guide-learn-blockchain.
[18] T. Montoya, Nonfungible tokens could change the way we own things, Available on, https://cointelegraph.com/news/nonfungible-tokens-could-change-the-way-we-own-things, 2020.
[19] Lisk - blockchain in real estate, Accessed: 10/11/2020; Available on, https://lisk.io/blog/research/blockchain-real-estate.
[20] Blockchain for commodities - trading opportunities in a digital age, Accessed: 02/12/2020; Available on, https://www.spglobal.com/en/research- insights/featured/blockchain-for-commodities-trading-opportunities-in-a-digital-age, 2018.
[21] Q&A, How blockchain could transform the art industry, Accessed: 10/11/2020; Available on, https://cointelegraph.com/news/qa-how-blockchain-could-transform-the-art-industry.
[22] 4ART technologies. Accessed: 10/11/2020; Available on: **Error! Hyperlink reference not valid.**.
[23] S. Manski, Distributed ledger technologies, value accounting, and the self sovereign identity, Front. Blockchain 3 (2020) 29, https://doi.org/10.3389/fbloc.2020.00029.
[24] Wang, F. and P.D. Filippi Self-sovereign identity in a globalized world: credentials-based identity systems as a driver for economic inclusion. Front. Blockchain. 2, 28 DOI: 10.3389/fbloc.2019.00028.
[25] X. Zigah, Is Bitcoin really digital gold?, Published: 11/05/2020; Accessed: 02/12/2020; Available on, https://www.forbes.com/sites/forbesfinancecouncil/2020/05/11/is-bitcoin- really-digital-gold/.
[26] J. Ducrée, M. Etzrodt, B. Gordijn, M. Gravitt, S. Bartling, R. Walshe, T. Harrington, Blockchain for organising effective grass-roots actions on a global commons: saving the planet, Front. Blockchain 3 (2020) 33, https://doi.org/10.3389/fbloc.2020.00033.
[27] THE (times higher education) world university rankings, Accessed: July 24; Available on, https://www.timeshighereducation.com/world-university-rankings.
[28] J.E. Hirsch, An index to quantify an individual's scientific research output, Proc. Natl. Acad. Sci. U. S. A. 102 (2005) 16569–16572, https://doi.org/10.1073/pnas.0507655102.
[29] T.K. Mackey, N. Shah, K. Miyachi, J. Short, K. Clauson, A framework proposal for blockchain-based scientific publishing using shared governance, Front. Blockchain 2 (2019), https://doi.org/10.3389/fbloc.2019.00019.
[30] J.v. Rossum, Blockchain for Research - Perspectives on a New Paradigm for Scholarly Communication, 2017. Accessed: 02/12/2020; Available on: Error! Hyperlink reference not valid.
[31] J. Brock, Could blockchain unblock science?, Accessed: 02/12/2020; Available on, https://www.natureindex.com/news-blog/could-blockchain-unblock-science, 2018.
[32] ARTiFACTS - researcher recognition, Accelerated. Accessed: 24/07/2020; Available on, https://artifacts.ai/.
[33] The bounties network - changing the way communities collaborate, Accessed: 02/12/2020; Available on, https://www.bounties.network/.
[34] Bounty0x - earning crypto made simple, Accessed: 27/07/2020; Available on, https://bounty0x.io/.
[35] T. Miyakawa, No raw data, no science: another possible source of the reproducibility crisis, Mol. Brain 13 (2020) 24, https://doi.org/10.1186/s13041-020-0552-2.
[36] K. Dwan, D.G. Altman, J.A. Arnaiz, J. Bloom, A.W. Chan, E. Cronin, E. Decullier, P.J. Easterbrook, E. Von Elm, C. Gamble, D. Ghersi, J.P. Ioannidis, J. Simes, P.R. Williamson, Systematic review of the empirical evidence of study publication bias and outcome reporting bias, PloS One 3 (2008), e3081, https://doi.org/10.1371/journal.pone.0003081.
[37] J.W. Schooler, Metascience could rescue the 'replication crisis', Nature 515 (2014) 9, https://doi.org/10.1038/515009a.
[38] D.B. Resnik, A.E. Shamoo, Reproducibility and research integrity, Account. Res. 24 (2017) 116–123, https://doi.org/10.1080/08989621.2016.1257387.
[39] L.P. Freedman, I.M. Cockburn, T.S. Simcoe, The economics of reproducibility in preclinical research, PLoS Biol. 13 (2015), e1002165, https://doi.org/10.1371/journal.pbio.1002165.
[40] BAT - basic attention token, Accessed: 17/08/2020; Available on, https://basicattentiontoken.org/.
[41] J. Surowiecki, The Wisdom of Crowds: Why the Many Are Smarter than the Few and How Collective Wisdom Shapes Business, Economies, Societies, and Nations, Random House, 2004.
[42] S. de la Rouviere, Introducing curation markets: trade popularity of memes & information (with code)!, Accessed: 24/07/2020; Available on, https://medium.com/@simondlr/introducing-curation-markets-trade-popularity-of-memes- information-with-code-70bf6fed9881, 2017.
[43] J. Goro, Token bonding curves explained, Accessed: July 24; Available on, https://medium.com/coinmonks/token-bonding-curves-explained-7a9332198e0e, 2018.
[44] Fab Labs, Accessed: 24/07/2020; Available on, https://www.fablabs.io/.
[45] J. Ducrée, Efficient development of integrated Lab-On-A-Chip systems featuring operational robustness and nanufacturability, Micromachines 10 (2019) 12, https://doi.org/10.3390/mi10120886.
[46] D.R. Reyes, H.v. Heeren, S. Guha, L.H. Herbertson, A.P. Tzannis, J. Ducrée, H. Bissig, H. Becker, Accelerating innovation and commercialization through standardization of microfluidic-based medical devices, Lab Chip (2020), https://doi.org/10.1039/D0LC00963F.
[47] Bloxberg, Blockchain infrastructure for scientific research, Accessed: 24/07/2020; Available on, https://bloxberg.org/.
[48] The LAO: a For-Profit, Limited Liability Autonomous Organization, 2019. Published: 03/09/2019; Accessed: 02/12/2020; Available on, https://medium.com/openlawofficial/the- lao-a-for-profit-limited-liability-autonomous-organization-9eae89c9669c.
[49] M.B. van der Waal, S.R.C. Dos, M. Ma, G.B. Haringhuizen, E. Claassen, L.H.M. van de Burgwal, Blockchain-facilitated sharing to advance outbreak R&D, Science 368 (2020) 719–721, https://doi.org/10.1126/science.aba1355.
[50] A. Telenti, X. Jiang, Treating medical data as a durable asset, Nat. Genet. (2020), https://doi.org/10.1038/s41588-020-0698-y.
[51] D. Heaven, Bitcoin for the biological literature, Nature 566 (2019) 141–142, https://doi.org/10.1038/d41586-019-00447-9.
[52] K. Janowicz, B. Regalia, P. Hitzler, G. Mai, S. Delbecque, M. Fröhlich, P. Martinent, T. Lazarus, On the prospects of blockchain and distributed ledger technologies for open science and academic publishing, Semantic Web 9 (2018) 545–555, https://doi.org/10.3233/sw-180322.
[53] DECENT, Accessed: 23/09/2020; Available on, https://decent.ch/.
[54] Wikipedia, Accessed: 02/12/2020; Available on, https://en.wikipedia.org/wiki/Main_Page.