Integration of Ontologies with Decentralized Autonomous Organizations Development: A Systematic Literature Review

María-Cruz Valiente(✉) and David Rozas

Institute of Knowledge Technology, Universidad Complutense de Madrid, Madrid, Spain
{mcvaliente,drozas}@ucm.es

Abstract. This paper presents a systematic literature review of the integration of ontologies into the Decentralized Autonomous Organization (DAO) development process. The review extracted data from 34 primary studies dealing with ontologies in the blockchain domain. DAO has become a key concept for the development of blockchain-based decentralized software systems. DAOs are seen as a positive alternative for organizations interested in the adoption of decentralized, reliable and transparent governance, as well as attracting the interest of academic research. However, there is no common understanding or generally accepted formal definition of a DAO, and the guidelines that provide support for the adoption and development of DAOs are limited to a few key references that lack the computational semantics needed to enable their automated validation, simulation or execution. Thus, the objective of this paper is to provide an unbiased and up-to-date review related to the integration of ontologies within DAOs which helps to identify new research opportunities and take advantage of this integration from a blockchain-based decentralized perspective.

Keywords: Ontology · DAO · Decentralized autonomous organization · Blockchain · Smart contract · Systematic literature review

1 Introduction

In the last decade, Decentralized Autonomous Organizations (DAOs) have gained increasing attention in industry and, in general, in the academic and public debate (e.g. American CryptoFed DAO[1] has been officially registered as the first DAO in Wyoming [1]). DAOs are being explored as a means of supporting organizations that ensure sharing, security, transparency, and auditability, making their governance or business models truly global without any central controlling authority or middleman.

DAOs appeared in the context of decentralized solutions with the creation of Ethereum [2], a general-purpose blockchain-based computing platform, as a way to explore new governance rules which could be automated, immutable and transparently embedded in a blockchain.

[1] https://www.americancryptofed.org/.

E. Garoufallou et al. (Eds.): MTSR 2021, CCIS 1537, pp. 171–184, 2022.
https://doi.org/10.1007/978-3-030-98876-0_15

In Ethereum, through the use of smart contracts (i.e. small pieces of code deployed on the blockchain and executed in a decentralized way by all the nodes in the network), DAOs can implement governance models and provide services (or resources) to third parties without the need for any intermediary [3].

However, DAO is still a term under development and it can be understood differently depending on the domain and the platform used [4, 5]. In this context, Liu et al. [6] identify and classify different proposals and perspectives closely related to the combination of DAO and blockchain technologies. Although this work could be a valuable source of information for the creation of ontologies related to DAO development, the review is not focused on the formalization process of this domain.

Currently, Moloch DAO [7], a DAO created to fund Ethereum 2.0 grants, and Aragon [8], a DAO that has implemented the most popular Ethereum-based framework for building DAOs, could be considered as de facto references, but they lack the computational semantics needed to enable their automated validation, simulation or execution.

In order to address this problem, ontologies have the potential to provide an agreed and common understanding of the term. Ontologies are widely used in the area of Software Engineering dealing with the process of software modeling aimed at the improvement of the software development process. An ontology is a formal term with a specific meaning from the real world and a related set of assumptions about that meaning [9]. More formally, an ontology defines the vocabulary of a problem domain and a set of constraints (axioms or rules) on how terms can be combined to model specific domains. Furthermore, ontologies are machine-processable models that have been used for decades to represent knowledge from our surroundings, producing domain-specific abstractions and an agreed understanding of the domain of interest.

Therefore, it seems that the integration of ontologies within the DAO domain may help software engineers and researchers understand, manage and build these types of complex blockchain-based decentralized organizations. That is, ontologies may provide a shared domain of conceptualizations representing knowledge that enable software engineers to model the problem as well as the solution for the subject of their investigations. As a result, ontologies have the potential to foster interoperability and support the extension of practices. In the existing literature, we find discussions about the contributions of ontologies to the implementation of decentralized approaches, for example, the research carried out by [10–13], among others.

Since we are interested in providing new solutions which deliver real benefits to developers of DAOs using ontologies, it is important to determine what type of research is being carried out and how it is conducted. Therefore, this paper presents a systematic literature review of the existing research related to the integration of ontologies into DAO development. The systematic literature review has been carried out following and adapting the protocols proposed in [14].

In this paper, Sect. 2 describes the plan of this systematic literature review, the research question, the sources used for the selection of primary studies, the search strings, the selection criteria and process, and the data that were considered for each primary study. Subsequently, Sect. 3 lists the selected primary studies. Based on the research questions, the discussion of the results is presented in Sect. 4. Finally, Sect. 5 contains the conclusion.

2 Systematic Literature Review Planning

2.1 Research Question

Since the objective of this systematic literature review is the identification of solutions related to the integration of ontologies into DAO development, the research question that was addressed by this work was the following: How can we use ontologies with blockchain-based decentralized technologies in order to support the adoption and building of DAOs?

2.2 Search Strategy

The selection of primary studies was based on a search of exclusively electronic sources. The primary studies selected were acquired from the following sources (in alphabetic order): (1) ACM Digital Library, (2) Elsevier Science Direct, (3) Google Scholar (this source was only used for searching specific papers that were cited in other primary studies), (4) IEEE Xplore, and (5) SpringerLink. These electronic sources were selected because they represent an important reference for software engineers and the industry in general.

From the research question, several search strings were defined: (1) "DAO" AND "Ontology"; (2) "Decentralized application" AND "Ontology"; (3) "Smart contract" AND "Ontology"; (4) "DAO" AND "Knowledge Graph"; (5) "Decentralized application" AND "Knowledge Graph"; and (6) "Smart contract" AND "Knowledge Graph".

It is worth highlighting two aspects regarding the search strategy. Firstly, the term "knowledge graph" was included since it was employed as a synonym of the term "ontology" in several articles. Secondly, the sources do not distinguish between singular and plural forms of the terms (e.g. ACM Digital Library). As a result, only singular terms were employed.

2.3 Primary Studies Selection

As recommended by [14], the primary studies selection was based on specific inclusion and exclusion criteria. The inclusion criteria considered studies where ontologies are used in blockchain-based decentralized approaches concerning the development of DAOs. These studies must provide contributions of ontologies to the DAO development process.

On the other hand, the exclusion criteria considered studies about DAO development and ontologies, in which there was no relation between them, or papers about blockchain-based decentralized approaches and ontologies, in which there was no relation to DAO development. Papers in which ontologies are used to improve the building of blockchain-based decentralized applications, but whose improvement is not related to the integration of ontologies within the DAO do-main, were also excluded.

The inclusion and exclusion criteria were applied to the title and abstract in order to determine if the research was considered relevant for the goals of this systematic literature review. However, when the title and abstract alone proved insufficient to determine the relevance of a text, the full text was reviewed.

The selection process for studies entailed several steps: (1) one researcher (the first author of this paper) applied the search strategy to identify potential primary studies, (2) several researchers checked titles and abstracts of all potential primary studies against the inclusion and exclusion criteria. If the title and abstract were not enough to determine how relevant a primary study was, then researchers reviewed the full text, and (3) any uncertainty in primary studies was discussed among the authors of this paper or with other researchers who have expertise in this domain. Each primary study remaining after the selection process of the systematic literature review was reviewed in detail and a review summary was written for each paper. The information of a review summary is defined in Table 1.

Table 1. Paper review summary.

Property	Value
Reference	Primary study ID
Source	The electronic source(s) where the primary study was found
Relevance	The relevance of the primary study to the research question (i.e., how well the primary study answers the research questions): {low, medium, high}
Title	The title of the primary study
Authors	The author(s) of the primary study
Publication	The details of the publication
Abstract	A summary of the primary study
Comments	Remarks and additional notes about the primary study

3 Data Synthesis

In recent years, there has been a growing effort to formalize the knowledge that underlies blockchain-based decentralized applications. However, it has been difficult to find relevant contributions and real implementations in this field of study. Most of them were blockchain-based conceptual or theoretical contributions pending validation or implementation of the proposed solutions. However, we included papers that, although focused on other topics not directly associated with DAOs, were considered as references for the integration of ontologies into the DAO development process.

The electronic sources provided 682 results. After applying the inclusion and exclusion criteria, 34 papers were considered to be primary studies for the research question. The total number of papers and the number of primary studies obtained from each electronic source can be seen in Table 2.

Table 2. Relevant information obtained from the electronic sources.

Electronic source	Papers (*)	Primary studies (**)
ACM Digital Library	61 (“DAO” AND “Ontology”) 3 (“Decentralized application” AND “Ontology”) 19 (“Smart contract” AND “Ontology”) 5 (“DAO” AND “Knowledge Graph”) 1 (“Decentralized application” AND “Knowledge Graph”) 3 (“Smart contract” AND “Knowledge Graph”)	9
Elsevier ScienceDirect	258 (“DAO” AND “Ontology”) 15 (“Decentralized application” AND “Ontology”) 56 (“Smart contract” AND “Ontology”) 2 (“DAO” AND “Knowledge Graph”) 2 (“Decentralized application” AND “Knowledge Graph”) 9 (“Smart contract” AND “Knowledge Graph”)	6
Google Scholar		2
IEEE Xplore	11 (“DAO” AND “Ontology”) 3 (“Decentralized application” AND “Ontology”) 10 (“Smart contract” AND “Ontology”) 0 (“DAO” AND “Knowledge Graph”) 0 (“Decentralized application” AND “Knowledge Graph”) 0 (“Smart contract” AND “Knowledge Graph”)	8
SpringerLink	41 (“DAO” AND “Ontology”) 4 (“Decentralized application” AND “Ontology”) 134 (“Smart contract” AND “Ontology”) 17 (“DAO” AND “Knowledge Graph”) 5 (“Decentralized application” AND “Knowledge Graph”) 23 (“Smart contract” AND “Knowledge Graph”)	9

(*) Date of search: June 2021.
(**) For a specific source, primary studies that were found in another source are not counted as primary studies.

The complete paper review summaries are excluded from this paper due to space limitation restrictions. Therefore, Table 3 shows the list of primary studies (Authors, Title, Relevance and Source) that were selected after the selection process.

Table 3. Selected studies grouped by source and publication date.

Authors	Title	Relev.	Source
Alex Norta, Anis Ben Othman, Kuldar Taveter	Conflict-Resolution Lifecycles for Governed Decentralized Autonomous Organization Collaboration	High	ACM [10]
Allan Third, John Domingue	Linked Data Indexing of Distributed Ledgers	High	ACM [15]
Michal R. Hoffman	Can Blockchains and Linked Data Advance Taxation?	Medium	ACM [16]
Marco Crepaldi	Why blockchains need the law	Low	ACM [17]
Leepakshi Bindra, Changyuan Lin, Eleni Stroulia, Omid Ardakanian	Decentralized Access Control for Smart Buildings Using Metadata and Smart Contracts	High	ACM [18]
Roberto García, Rosa Gil	Social Media Copyright Management using Semantic Web and Blockchain	High	ACM [19]
Manoharan Ramachandran, Niaz Chowdhury, Allan Third, John Domingue, Kevin Quick, Michelle Bachler	Towards Complete Decentralised Verification of Data with Confidentiality: Different ways to connect Solid Pods and Blockchain	Low	ACM [20]
Haan Johng, Doohwan Kim, Grace Park, Jang-Eui Hong, Tom Hill, Lawrence Chung	Enhancing Business Processes with Trustworthiness using Blockchain: A Goal-Oriented Approach	High	ACM [21]
Hongman Wang, Yongbin Yuan, Fangchun Yang	A Personal Data Determination Method Based On Blockchain Technology and Smart Contract	Low	ACM [22]
Athina-Styliani Kleinaki, Petros Mytis-Gkometh, George Drosatos, Pavlos S. Efraimidis, Eleni Kaldoudi	A Blockchain-Based Notarization Service for Biomedical Knowledge Retrieval	Low	Elsevier [23]
Zhengxin Chen	Understanding Granular Aspects of Ontology for Blockchain Databases	Low	Elsevier [24]

(*continued*)

Table 3. (*continued*)

Authors	Title	Relev.	Source
Wout J. Hofman	A Methodological Approach for Development and Deployment of Data Sharing in Complex Organizational Supply and Logistics Networks with Blockchain Technology	High	Elsevier [25]
Alex Roehrs, Cristiano André da Costa, Rodrigo da Rosa Righi, Valter Ferreira da Silva, José Roberto Goldim, Douglas C. Schmidt	Analyzing the performance of a blockchain-based personal health record implementation	High	Elsevier [26]
Hans Weigand, Ivars Blums, Joost de Kruijff	Shared Ledger Accounting - Implementing the Economic Exchange pattern	High	Elsevier [27]
Xiaochi Zhou, Mei Qi Lim, Markus Kraft	A Smart Contract-based agent marketplace for the J-Park Simulator - a knowledge graph for the process industry	Low	Elsevier [28]
Henry M. Kim, Marek Laskowski	Toward an Ontology-Driven Blockchain Design for Supply Chain Provenance	High	Google [11]
Henry M. Kim, Marek Laskowski, Ning Nan	A First Step in the Co-Evolution of Blockchain and Ontologies: Towards Engineering an Ontology of Governance at the Blockchain Protocol Level	High	Google [12]
Darra L. Hofman	Legally Speaking: Smart Contracts, Archival Bonds, and Linked Data	High	IEEE [29]
Olivia Choudhury, Nolan Rudolph, Issa Sylla, Noor Fairoza, Amar Das	Auto-Generation of Smart Contracts from Domain-Specific Ontologies and Semantic Rules	High	IEEE [30]
Alex Norta	Self-Aware Smart Contracts with Legal Relevance	High	IEEE [31]
Hamza Baqa, Nguyen B. Truong, Noel Crespi, Gyu Myoung Lee, Franck Le Gall	Semantic Smart Contracts for Blockchain-based Services in the Internet of Things	High	IEEE [32]

(*continued*)

Table 3. (*continued*)

Authors	Title	Relev.	Source
Mengyi Li, Lirong Xiay, Oshani Seneviratne	Leveraging Standards Based Ontological Concepts in Distributed Ledgers: A Healthcare Smart Contract Example	High	IEEE [33]
Wim Laurier	Blockchain Value Networks	High	IEEE [34]
Seung-Min Lee, Soojin Park, Young B. Park	Formal Specification Technique in Smart Contract Verification	High	IEEE [35]
Panos Kudumakis, Thomas Wilmering, Mark Sandler, Víctor Rodríguez-Doncel, Laurent Boch, Jaime Delgado	The Challenge: From MPEG Intellectual Property Rights Ontologies to Smart Contracts and Blockchains	High	IEEE [36]
Alex Norta	Creation of Smart-Contracting Collaborations for Decentralized Autonomous Organizations	Low	SpringerLink [37]
Alex Norta, Lixin Ma, Yucong Duan, Addi Rull, Merit Kõlvart and Kuldar Taveter	eContractual choreography-language properties towards cross-organizational business collaboration	High	SpringerLink [38]
Nanjangud C. Narendra, Alex Norta, Msury Mahunnah, Lixin Ma, Fabrizio Maria Maggi	Sound conflict management and resolution for virtual-enterprise collaborations	High	SpringerLink [39]
Elena García-Barriocanal, Salvador Sánchez-Alonso, Miguel-Angel Sicilia	Deploying Metadata on Blockchain Technologies	Low	SpringerLink [40]
Joost de Kruijff, Hans Weigand	Understanding the Blockchain Using Enterprise Ontology	High	SpringerLink [41]
Joost de Kruijff, Hans Weigand	Ontologies for Commitment-Based Smart Contracts	High	SpringerLink [42]
Jan Ladleif, Mathias Weske	A Unifying Model of Legal Smart Contracts	Low	SpringerLink [43]
Elena García-Barriocanal, Miguel-Ángel Sicilia, Salvador Sánchez-Alonso	The Case for Ontologies in Expressing Decisions in Decentralized Energy Systems	Medium	SpringerLink [44]

(*continued*)

Table 3. (*continued*)

Authors	Title	Relev.	Source
Diogo Silva, Sérgio Guerreiro, Pedro Sousa	Decentralized Enforcement of Business Process Control Using Blockchain	High	SpringerLink [13]

4 Discussion

In this section, we present the relevant information gathered that answers the research question of this systematic literature review: How can ontologies be used with blockchain-based decentralized technologies in order to support the adoption and building of DAOs?

After the analysis and evaluation of the primary studies, we found several approaches that could apply ontologies to DAO development. Most of the studies use ontologies in the context of governance. For example, Garcia and Gil [19] propose the use of an ontology in order to formalize key copyright concepts that, although not applied to DAOs, is suitable for rights management modeling in a specific DAO. Another example can be found in Kim et al. [12], who propose a conceptual design of a governance ontology represented as meta-data tags to be embedded and instantiated in a blockchain-based smart contract solution. We can also find several studies related to the formalization of legal aspects involved in smart contracts such as the implementation of a socio-technical system of rules as established by legal theorists [17], aspects related to the tax gap [16], decentralized peer-to-peer (P2P) economy in terms of obligations and rights [31] and a semantic legal layer [29, 32].

Another line of research is focused on cross-organizational businesses whose governance involves the use of DAOs. In this line, DAOs are employed in the management of eCommunities [10], to access cloud computing services [37], to allow contractual flexibility [38], and to support conflict resolution management [39], to name but a few. In the same context, Silva et al. [13] present a proposal that tackles the problem of traceability and management in collaborative business processes.

Another common approach is the of use ontologies for domain modeling through the implementation of smart contracts which are part of a DAO (e.g. business transactions [25], distributed and interoperable personal records [26] and accounting and financial reporting [27]).

Finally, another general approach, although less explored, proposes ontologies for the modeling of blockchain (and smart contract) concepts such as the work presented in [15], which could provide support for technical issues concerning DAO development.

Figure 1 shows the number of studies focused on each research topic according to the publication year. Since legal aspects and governance rules may be successfully described by ontologies, the 'governance' category represents the most important research topic related to DAO development [45]. It is worth noting that research related to governance started to gain importance particularly since the appearance of the Ethereum platform and the concept of DAO. On the other hand, due to the proliferation of blockchain-based

decentralized applications, such as DAOs, research related to domain modeling has seen increasing interest in the last two years.

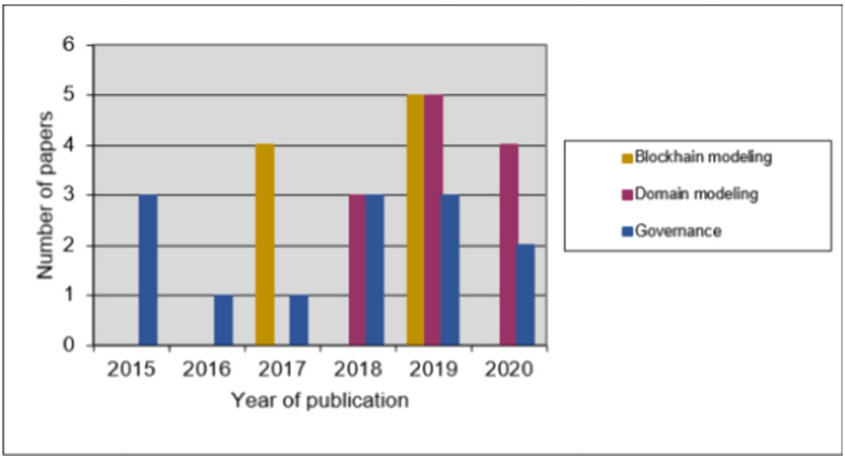

Fig. 1. Number of studies covering each topic based on the publication year.

In summary, from a DAO development perspective, although we could not find proposals that explicitly apply ontologies in the formalization of the term, ontologies could be integrated within DAOs in three ways: (1) using ontologies as a tool for the management of governance in decentralized organizations; (2) using ontologies for business domains or governance rules modeling; and, at a general level, (3) using ontologies as a formalization of technical aspects concerning blockchain technology.

5 Conclusions

Our research responds to an increasing interest in and adoption of DAOs as a new approach for the implementation of blockchain-based online organizations, where establishing a consensus and a common understanding without ambiguities and contradictions (i.e. formalization) is of major importance.

In this paper, we have answered the research question presented in Sect. 2 by offering an insight into recent research on the integration of ontologies into DAO development in order to identify new research challenges to be explored.

This systematic literature review provides up-to-date information on how ontologies could be integrated within DAOs from a blockchain-based decentralized perspective. The findings reveal:

- The contribution that ontologies make to DAO development. That is, how ontologies may help to describe knowledge related to blockchain-based decentralized applications that could be reused to build similar or more complex ones.

- Ontology-based approaches that can be applied across several interrelated blockchain-based decentralized application knowledge areas (e.g. legal aspects, governance rules modeling, technical issues), and that could be extrapolated to DAOs in a seamless manner.
- The existing ontologies created to define specific domains aimed at solving different problems and gaps related interoperability and data sharing in several business scenarios in a blockchain-based decentralized way (e.g. personal and health data, supply and logistics information, and energy systems).

These results indicate a growing interest in the integration of ontologies with different aspects of blockchain-based decentralized applications. We have observed that ontologies could play an important role in the DAO development process. Moreover, the formalization of this term could help to improve the development of tools and frameworks that provide support to adopt this new governance approach.

Acknowledgments. This work was partially supported by the project P2P Models (https://p2pmodels.eu) funded by the European Research Council ERC-2017-STG [grant no.: 759207]; and by the project Chain Community funded by the Spanish Ministry of Science, Innovation and Universities [grant no.: RTI2018-096820-A-100].

References

1. America's First Legal DAO Approved in Wyoming, 5 July 2021. https://decrypt.co/75222/americas-first-dao-approved-in-wyoming. Accessed 16 Aug 2021
2. Buterin, V.: A next-generation smart contract and decentralized application platform. https://blockchainlab.com/pdf/Ethereum_white_paper-a_next_generation_smart_contract_and_decentralized_application_platform-vitalik-buterin.pdf. Accessed 16 Aug 2021
3. Hassan, S.: P2P Models white paper. Decentralized Blockchain-based Organizations for Bootstrapping the Collaborative Economy (2017). https://p2pmodels.eu/wp-content/uploads/whitepaper_p2pmodels.pdf. Accessed 16 Aug 2021
4. Hassan, S., De Filippi, P.: Decentralized autonomous organization. Internet Policy Rev. **10**(2) (2021). https://doi.org/10.14763/2021.2.1556
5. El Faqir, Y., Arroyo, J., Hassan, S.: An overview of decentralized autonomous organizations on the blockchain. In: Proceedings of the 16th International Symposium on Open Collaboration (OpenSym 2020), New York, NY, USA, Article 11, pp. 1–8. Association for Computing Machinery (2020). https://doi.org/10.1145/3412569.3412579
6. Liu, L., Zhou, S., Huang, H., Zheng, Z.: From technology to society: an overview of blockchain-based DAO. IEEE Open J. Comput. Soc. **2**(1), 204–215. (2021). https://doi.ieeecomputersociety.org/10.1109/OJCS.2021.3072661
7. MolochDAO. https://molochdao.com/. Accessed 16 Aug 2021
8. Aragon. https://aragon.org/. Accessed 16 Aug 2021
9. Guarino, N.: Formal Ontology and Information Systems (1998). http://www.loa.istc.cnr.it/old/Papers/FOIS98.pdf. Accessed 16 Aug 2021
10. Norta, A., Othman, A.B., Taveter, K.: Conflict-resolution lifecycles for governed decentralized autonomous organization collaboration. In: Proceedings of the 2015 2nd International Conference on Electronic Governance and Open Society: Challenges in Eurasia - EGOSE 2015, St. Petersburg, Russian Federation, pp. 244–257. ACM Press. (2015). https://doi.org/10.1145/2846012.2846052

11. Kim, H.M., Laskowski, M.: Towards an ontology-driven blockchain design for supply chain provenance. Int. Syst. Account. Finance Manag. (2018). https://doi.org/10.1002/isaf.1424
12. Kim, H.M., Laskowski, M., Nan, N.: A first step in the co-evolution of blockchain and ontologies: towards engineering an ontology of governance at the blockchain protocol level. arXiv:180102027 (2018)
13. Silva, D., Guerreiro, S., Sousa, P.: Decentralized enforcement of business process control using blockchain. In: Aveiro, D., Guizzardi, G., Guerreiro, S., Guédria, W. (eds.) EEWC 2018. LNBIP, vol. 334, pp. 69–87. Springer, Cham (2019). https://doi.org/10.1007/978-3-030-06097-8_5
14. Kitchenham, B.: Guidelines for performing systematic literature reviews in software engineering (Version 2.3). EBSE Technical report: EBSE-2007-01. Software Engineering Group, School of Computer Science and Mathematics, Keele University, Staffordshire (2007)
15. Third, A., Domingue, J.: Linked data indexing of distributed ledgers. In: Proceedings of the 26th International Conference on World Wide Web Companion - WWW 2017 Companion, Perth, Australia, pp. 1431–1436. ACM Press (2017). https://doi.org/10.1145/3041021.3053895
16. Hoffman, M.R.: Can blockchains and linked data advance taxation. In: Companion of the Web Conference 2018 - WWW 2018, Lyon, France, pp. 1179–1182. ACM Press (2018). https://doi.org/10.1145/3184558.3191555
17. Crepaldi, M.: Why blockchains need the law: Secondary rules as the missing piece of blockchain governance. In: Proceedings of the Seventeenth International Conference on Artificial Intelligence and Law, Montreal, QC, Canada, pp. 189–193. ACM Press (2019). https://doi.org/10.1145/3322640.3328780
18. Bindra, L., Lin, C., Stroulia, E., Ardakanian, O.: Decentralized access control for smart buildings using metadata and smart contracts. In: 2019 IEEE/ACM 5th International Workshop on Software Engineering for Smart Cyber-Physical Systems (SEsCPS) , Montreal, QC, Canada, pp. 32–38. IEEE (2019). https://doi.org/10.1109/SEsCPS.2019.00013
19. García, R., Gil, R.: Social media copyright management using semantic web and blockchain. In: Proceedings of the 21st International Conference on Information Integration and Web-Based Applications & Services, Munich Germany, pp. 339–343. ACM (2019). https://doi.org/10.1145/3366030.3366128
20. Ramachandran, M., Chowdhury, N., Third, A., Domingue, J., Quick, K., Bachler, M.: Towards complete decentralised verification of data with confidentiality: different ways to connect solid pods and blockchain. In: Companion Proceedings of the Web Conference 2020, Taipei Taiwan, pp. 645–649. ACM (2020). https://doi.org/10.1145/3366424.3385759
21. Johng, H., Kim, D., Park, G., Hong, J.-E., Hill, T., Chung, L.: Enhancing business processes with trustworthiness using blockchain: a goal-oriented approach. In: Proceedings of the 35th Annual ACM Symposium on Applied Computing, pp. 61–68 (2020). https://doi.org/10.1145/3341105.3374022
22. Wang, H., Yuan, Y., Yang, F.: A personal data determination method based on blockchain technology and smart contract. In: Proceedings of the 2020 4th International Conference on Cryptography, Security and Privacy, Nanjing China, pp. 89–94. ACM (2020). https://doi.org/10.1145/3377644.3377656
23. Kleinaki, A.-S., Mytis-Gkometh, P., Drosatos, G., Efraimidis, P.S., Kaldoudi, E.: A blockchain-based notarization service for biomedical knowledge retrieval. Comput. Struct. Biotechnol. J. **16**, 288–297 (2018). https://doi.org/10.1016/j.csbj.2018.08.002
24. Chen, Z.: Understanding granular aspects of ontology for blockchain databases. Procedia Comput. Sci. **162**, 361–367 (2019). https://doi.org/10.1016/j.procs.2019.11.296
25. Hofman, W.J.: A methodological approach for development and deployment of data sharing in complex organizational supply and logistics networks with blockchain technology. IFAC-Pap. **52**, 55–60 (2019). https://doi.org/10.1016/j.ifacol.2019.06.010

26. Roehrs, A., da Costa, C.A., da Rosa Righi, R., da Silva, V.F., Goldim, J.R., Schmidt, D.C.: Analyzing the performance of a blockchain-based personal health record implementation. J. Biomed. Inform. **92**, 103140 (2019). https://doi.org/10.1016/j.jbi.2019.103140
27. Weigand, H., Blums, I., de Kruijff, J.: Shared ledger accounting - implementing the economic exchange pattern. Inf. Syst. **90**, 101437 (2020). https://doi.org/10.1016/j.is.2019.101437
28. Zhou, X., Lim, M.Q., Kraft, M.: A Smart Contract-based agent marketplace for the J-Park Simulator - a knowledge graph for the process industry. Comput. Chem. Eng. **139**, 106896 (2020). https://doi.org/10.1016/j.compchemeng.2019.106577
29. Hofman, D.L.: Legally speaking: smart contracts, archival bonds, and linked data in the blockchain. In: 26th International Conference on Computer Communication and Networks, Vancouver, BC, Canada, pp. 1–4 (ICCCN). IEEE (2017). https://doi.org/10.1109/ICCCN.2017.8038515
30. Choudhury, O., Rudolph, N., Sylla, I., Fairoza, N., Das, A.: Auto-generation of smart contracts from domain-specific ontologies and semantic rules. In: 2018 IEEE International Conference on Internet of Things (IThings) and IEEE Green Computing and Communications (GreenCom) and IEEE Cyber, Physical and Social Computing (CPSCom) and IEEE Smart Data (SmartData) , Halifax, NS, Canada, pp. 963–970. IEEE (2018). https://doi.org/10.1109/Cybermatics_2018.2018.00183
31. Norta, A.: Self-aware smart contracts with legal relevance. In: 2018 International Joint Conference on Neural Networks (IJCNN), Rio de Janeiro, pp. 1–8. IEEE (2018). https://doi.org/10.1109/IJCNN.2018.8489235
32. Baqa, H., Truong, N.B., Crespi, N., Lee, G.M., le Gall, F.: Semantic smart contracts for blockchain-based services in the internet of things. In: IEEE 18th International Symposium on Network Computing and Applications (NCA), pp. 1–5 (2019). https://doi.org/10.1109/NCA.2019.8935016
33. Li, M., Xia, L., Seneviratne, O.: Leveraging standards based ontological concepts in distributed ledgers: a healthcare smart contract example. In: IEEE International Conference on Decentralized Applications and Infrastructures, Newark, CA, USA, pp. 152–157. IEEE (2019). https://doi.org/10.1109/DAPPCON.2019.00029
34. Laurier, W., Kiehn, J., Polovina, S.: REA2: a unified formalisation of the Resource-Event-Agent ontology. Appl. Ontol. **13**, 201–224 (2018). https://doi.org/10.3233/AO-180198
35. Lee, S.-M., Park, S., Park, Y.B.: Formal specification technique in smart contract verification. In: International Conference on Platform Technology and Service (PlatCon) , Jeju, Korea (South), pp. 1–4. IEEE (2019). https://doi.org/10.1109/PlatCon.2019.8669419
36. Kudumakis, P., Wilmering, T., Sandler, M., Rodriguez-Doncel, V., Boch, L., Delgado, J.: The challenge: from MPEG intellectual property rights ontologies to smart contracts and blockchains [standards in a nutshell]. IEEE Signal Process. Mag. **37**, 89–95 (2020). https://doi.org/10.1109/MSP.2019.2955207
37. Norta, A.: Creation of smart-contracting collaborations for decentralized autonomous organizations. In: Matulevičius, R., Dumas, M. (eds.) BIR 2015. LNBIP, vol. 229, pp. 3–17. Springer, Cham (2015). https://doi.org/10.1007/978-3-319-21915-8_1
38. Norta, A., Ma, L., Duan, Y., Rull, A., Kõlvart, M., Taveter, K.: eContractual choreography-language properties towards cross-organizational business collaboration. J. Internet Serv. Appl. **6**(1), 1–23 (2015). https://doi.org/10.1186/s13174-015-0023-7
39. Narendra, N.C., Norta, A., Mahunnah, M., Ma, L., Maggi, F.M.: Sound conflict management and resolution for virtual-enterprise collaborations. SOCA **10**(3), 233–251 (2015). https://doi.org/10.1007/s11761-015-0183-0
40. García-Barriocanal, E., Sánchez-Alonso, S., Sicilia, M.-A.: Deploying metadata on blockchain technologies. In: Garoufallou, E., Virkus, S., Siatri, R., Koutsomiha, D. (eds.) Metadata and Semantic Research. CCIS, vol. 755, pp. 38–49. Springer, Cham (2017). https://doi.org/10.1007/978-3-319-70863-8_4

41. de Kruijff, J., Weigand, H.: Understanding the blockchain using enterprise ontology. In: Dubois, E., Pohl, K. (eds.) Advanced Information Systems Engineering. LNCS, vol. 10253, pp. 29–43. Springer, Cham (2017). https://doi.org/10.1007/978-3-319-59536-8_3
42. de Kruijff, J., Weigand, H.: Ontologies for commitment-based smart contracts. In: Panetto, H., et al. (eds.) On the Move to Meaningful Internet Systems. OTM 2017 Conferences. LNCS, vol. 10574, pp. 383–398. Springer, Cham (2017). https://doi.org/10.1007/978-3-319-69459-7_26
43. Ladleif, J., Weske, M.: A unifying model of legal smart contracts. In: Laender, A.H.F., Pernici, B., Lim, E.-P., de Oliveira, J.P.M. (eds.) ER 2019. LNCS, vol. 11788, pp. 323–337. Springer, Cham (2019). https://doi.org/10.1007/978-3-030-33223-5_27
44. García-Barriocanal, E., Sicilia, M., Sánchez-Alonso, S.: The case for ontologies in expressing decisions in decentralized energy systems. In: Garoufallou, E., Sartori, F., Siatri, R., Zervas, M. (eds.) Metadata and Semantic Research. CCIS, vol. 846, pp. 365–376. Springer, Cham (2019). https://doi.org/10.1007/978-3-030-14401-2_35
45. Risius, M., Spohrer, K.: A blockchain research framework. Bus. Inf. Syst. Eng. **59**(6), 385–409 (2017). https://doi.org/10.1007/s12599-017-0506-0