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REVIEW OF SMART CONTRACTS FOR CLOUD-BASED MANUFACTURING

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Abstract. Cloud-based manufacturing is taking shape, and many industries seem interested to make the transition to it. Developing blockchain solutions for trusted computing is also taking its roots. Developing a blockchain-based solution for cloud-based manufacturing systems is a field that is new but also faces limitations and a lack of case studies. Smart contracts are one part of the solution which deals with making blockchain successful in cloud-based manufacturing. As we move towards smart contracts design and development for cloud-based manufacturing, there is no complete survey of smart contract and cloud manufacturing that can highlight critical, challenging issues and limitations. Most of the work found in smart contracts is mostly financial and notary-centric applications. On the cloud manufacturing side, most of the literature deals with Internet of Things (IoT) and cloud computing systems. Therefore, there is a need to study the best practices to start manufacturing supported by blockchain smart contracts. We conducted a scoping review for smart contracts for cloud manufacturing to address the problem mentioned above. We studied the latest case studies and concepts in data extracted from digital libraries and online repositories. Furthermore, we follow the relevance and acceptance criteria of research articles for inclusion and exclusion from this work. This paper focuses on blockchain systems, smart contracts and architecture, smart contracts in the cloud, and the IoT environment. Furthermore, we tried to bridge design and implementation details for readers to understand the patterns that can replicate for cloud-based manufacturing systems.

Keywords: Smart contract, blockchain, cloud manufacturing, cloud computing

1 INTRODUCTION

The rise of the internet has given new ways of working and integrating this world. The internet offered faster and accurate ways of working by interacting with their computers, sending, and receiving data on a computer, and interpreting the data. With the transformation of browsers, application platforms, and a comprehensive operating system, the network-centric nature of work has been the outcome of the internet driven work. There has been a change in society with the advent of the information-enabled world. As there have been changing work patterns of people working on network-centric organizations, there has been a change in the social fabric. The network age brought the information abundance age with itself. As information increased, so its consumption and impact on society changed. A transition from printed information to radio, TV and the internet brought its level of trust issues. The social media age and applications related to it created a level of trust issues with its consumers. As societies processed, became network-centric and changed the way we work, there was an imperative need for a trusted information system. Ever since recent times, academia and industry are striving for a trustable system to meet the demands of the present time.

We know that manufacturing has been ever-present with technological backing from the start of this century. When we look at manufacturing in the internet age, internet-driven manufacturing increased work quality and quantum output. Similarly, the manufacturing industry inherits change from the sectors discussed before, the change in society, and the working mechanism. Further manufacturing across the continent requires understanding that the social needs and internet infrastructure worldwide are not similar. As it possesses inherent trust issues in manufacturing, we believe that trust issues are still present in a manufacturing system in an internet-enabled world.

The internet offers the benefits of quick collaboration and data management/ optimizations. The faster and shared working environment provided new business opportunities for every sector, such as healthcare, manufacturing, education, entertainment, and software development, to name a few. Cloud-based operations are fast becoming standard for organizations that aim at effective resource management and better collaboration among employees. Nevertheless, these technologies bring changes associated with them. Therefore, it is imperative to understand cloud-based operations' challenges and limitations and explore opportunities to develop future systems that address the concerns. As the internet coverage and application increased, there were inherent trust issues with data and transactions carried out. Therefore, a peer-to-peer network-based, consensus-driven, trust-building technology emerged on the horizon of the technology world, called a blockchain. We have witnessed the exponential growth of blockchain operations and their application for trust-building factors. Blockchain is a technology, which works on the peer-to-peer-based network, mutual greed transaction that results in a trusted transaction. Blockchain started as bitcoin, but later more entities added up for the transaction.

Property papers, medical records, academic results, and various important documents can be part of the chain.

Academia and the industry are currently working towards developing blockchain-based trust enterprise systems and improving blockchain technology. The improvements in blockchain technology involve developments of dApps and Smart contracts (we will discuss later). They are further improving the advancement of IDE (integrated development environments) and testing platforms. The overall impact of any technology cannot be predicted 100 % accurately, but trust established by blockchain at a strategic level, integrative tools that facilitate application development across domains, is still a challenge. New transaction standards, technology, quality of service, and authenticity will emerge when blockchain drive recess occurs. As blockchain services are consensus-driven processes, there can potentially increase the dependency of all stakeholders in the concocts building process. Further, the dependency of cryptographic and mining processes can provide a limitation. Having limitation insight, the process can be set to a value for price for providing a high quality of the transaction. Blockchain will enable and trigger cryptographic algorithms better suited for future needs. Further, as new blockchain applications emerge, such as blockchain-based agriculture, oil and gas transaction, and legal processes, completely novel applications will be re-engineered for the process. Blockchain and Manufacturing Industry is currently transitioning towards intelligent, automated, and network-centric operations. However, this transition is not smooth and trustable in all sections and all parts of the world. The blockchain-enabled transition will add the needed trust in manufacturing operation by enabled people and software-driven trust in the process and data of the manufacturing domain. In public sector organizations, procurement services are already driven by a consensus-driven procurement process for transparency. The idea of a consensus-driven process brings benefits of transparency-driven trust and value for resources. The idea of blockchain is almost identical to it, but it involves digital elements to conduct the process.

Like procurement, maintenance services, when service providers and revise recovery are part of the same consensus-driven service delivery, the services delivery becomes more trustable and can engage all stakeholders rightly in the process. Applying this analogy to blockchain-driven service delivery can deduce that future applications such as government services delivery and software-as-a-service quality can be guaranteed. An important part of service delivery is agreement or satisfaction by the users. If users are part of the consensus completing a service delivery transaction, the delivery of services becomes trustable through blockchain. Due to trustable and consensus-based transactions, blockchain-based operations in the industry may be low-cost. The low cost of operation might be due to checks and balances at each step up to services delivery of the product. Contracts and encryption are not only pillars of reliability in the blockchain process but process immutability as well. The reliability of manufacturing recess will change the process controls to more reliable ones. It ensures better data control and more trust among stakeholders. This trust and data control are essential when transactions are carried out in a network where more unknown entities are involved.

Blockchain-based platforms are still in the infancy of adoption. There is a need for better programming languages, more support for established programming languages, programming paradigms, integrated development environment, and testing facilities for blockchain-based applications to see substantial positive change in the future.

1.1 Smart Contracts and Blockchain

Smart contracts form core components of the blockchain ecosystem. Novel design patterns are required for emerging markets that employ blockchain-based solutions. Specific to cloud-based manufacturing, new design patterns will change ember when cloud-based manufacturing takes roots as soon as new case studies are visible and successful and state-of-the-art becomes an advocating point for implementing a blockchain-based smart contract. Corporate and social support for blockchain-enabled processes will change in its favor when they see substantial impacts and results after its application. Trust is an expensive entity; implementing a blockchain-based solution will make trust a pervasive entity. Very few studies have been done on cloud-based manufacturing and blockchain implementations. Furthermore, there is also little information on a detailed study on smart contracts for such systems. This study will address a detailed discussion on tools and testing for making such smart contracts, specifically for cloud-based manufacturing. In discussing smart contracts, we will elaborate on trends and patterns that can help industrial developers and the academic environment.

This literature review will help cloud-based manufacturing software developers to plan and implement blockchain-based solutions in their establishments. Furthermore, smart contracts that will focus on the could base manufacturing setups. This study will help software engineers transition to a blockchain solution. For researchers, it is important to develop experiments that can advance research work activity. This study also facilitates understanding for legal and business communities to understand and explore more smart contracts. Smart contract's understandability to various stakeholders can help blockchain technology perception improve and help blockchain-based implementation increase in cloud-based manufacturing.

Testing platforms and development environments for smart contracts is crucial. This review will cover and bind basic definitions and implement details of blockchain and cloud-based manufacturing. Further, we will be discussing smart contracts for cloud-based manufacturing and the issues associated with them. Further, there will be a detailed discussion on the nature and implantation details of programming paradigms, integrated development environments for developing smart contracts for cloud manicuring. Last but not least, we will be discussing possible design patterns for smart contracts for cloud and manufacturing. This study consists of five sections – Section 2 covers background work, Section 3 covers the method used to conducts a literature review. Section 4 covers result from the systemic process, and Section 5 covers a discussion on smart contracts and its implementations tools and frameworks. Section 6 concludes the paper and draws future research direction.

2 BACKGROUND

This section provides a background to contextualize the scoping review and explains key attributes of the recommender systems, followed by an overview of the research landscape that encompasses key journals, books, and publications. This section covers a background description of cloud base manufacturing, blockchain, and smart contracts.

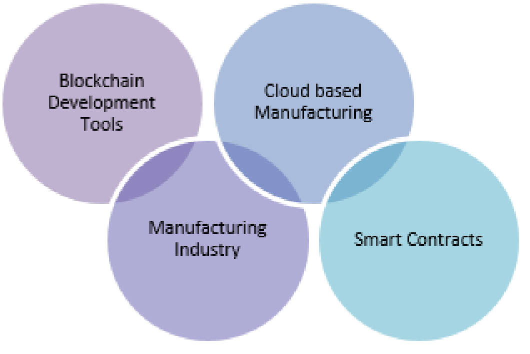

Figure 1. Topics covered by the review

2.1 Cloud and Manufacturing

Cloud-based manufacturing has gained attention in recent years, this work presents the pioneering work [1]. The work titled "old wine in new bottles" investigates the evolution of manufacturing to cloud-based manufacturing. The authors define cloud-based manufacturing as "a form of decentralized and networked manufacturing evolving from other relevant manufacturing systems such as web- and agent-based manufacturing." The article discusses the transition of the manufacturing industry from assembly line manufacturing setups that primarily focused on increasing production rate to cloud-based manufacturing that focuses on some new principles. These principles include ubiquitous and pervasive computing, information sharing and improved resource utilization, and reduced product delivery time. The authors present key characteristics of cloud base manufacturing. The key characteristics are scalable, agile, ubiquitous computing. It also includes infrastructure, platform, hardware, and software as a service. Furthermore, it also reports characteristics of big data and crowdsourcing. The authors also report that cloud-based manufacturing is a new paradigm, and there is a need to redefine many new sectors in computer science and information technology to redevelop its elements.

The study about blockchain [2] recognizes the rise of cloud-based manufacturing in this decade. The authors focus on key concepts governing the blocking such as operational models, service models, architecture, and essential services. Furthermore, the authors discuss the relationship between cloud manufacturing, cyber-physical systems, and smart manufacturing. The study also involves the understanding relationship with Industry 4.0. The study defines that cloud manufacturing is an extension of cloud computing. As cloud computing evolves, it builds on the concept of software as a service, platform as a service, infrastructure as a service, and manufacturing as a service. Further, they advocate that cloud manufacturing supports two aspects: resource sharing in manufacturing and business collaboration. The services cloud-based manufacturing could offer can be a design, production, fabrication, simulation, test, maintenance, management, and integration as a service. Finally, the authors establish that cloud-based manufacturing contributes towards the idea of smart manufacturing Industry 4.0.

Therefore, we conclude that cloud-based manufacturing provides a much-promised transition to next-generation manufacturing capabilities and builds the potential to develop more complex and sophisticated products by leveraging cloud computing technologies. It is important to understand that cloud computing provides a baseline technology and a bridging technology in transitioning to next-generation manufacturing.

2.2 Blockchain Technology

In this section, we introduce some aspects of the blockchain system. This section will orient the users on how blockchain-based systems change the current trends and impact future technologies. We will discuss blockchain-based cloud manufacturing, blockchain and the internet of things, blockchain and games, artificial intelligence, and blockchain.

Another study on blockchain [3] has described its structure in detail. The authors follow the definition of Lee Kuo Chen about blockchain, such as, blockchain is defined as “a sequence of the block, which holds a complete list of transactions of records life public ledger.” The author describes that blockchain starts with a genesis block and keeps growing based on records. It has certain elements such as timestamp, block version, and nonce that define blockchain structure. Further, blockchain has encryption mechanisms, public and private, that help blockchain maintain security and privacy. They are also called digital signatures. The authors further elaborate the blockchain structure. The state that blockchain structure has internet elements of decentralization, a confirmation-based transacting called persistency, an address-based interaction in network, and validations of records based on timestamp. Therefore, these elements provide blockchain an inherent value. Further, the authors describe the taxonomy of blockchains, such as public blockchain, consortium blockchain, and private blockchain. A public blockchain is open to all miners, a consortium blockchain is open to selected organizations, and a private blockchain is open to one organization. Blockchain technology is consensus-driven technology.

Therefore, there are various consensus mechanisms that blockchain technology uses. The authors describe that one of the most used is proof of work, a strategy of concensus building that requires miners to competing to write the next block into the blockchain. The largest chain is considered authentic. Other consensus mechanism is proof of stake, delegated proof of stake, Ripple, practical byzantine fault tolerance. Consensus mechanisms are selected for implementation based on certain properties such as energy management or based on a threshold value, to name a few. The study [4] presents a novel system called DCM App, a decentralized cloud manufacturing application. The application runs on the Ethereum network. The application maintains transparency during the manufacturing process. Furthermore, it also makes sure that manufacturing is an economic and safety-based process. This work is based on some problems as identified by the authors. These problems are over test on centralization of computer systems and a need for an intermediary that can be trusted. Further, it also highlights that cloud-based manufacturing responsibility management and user control issues are some design challenges that the proposed work addresses. Furthermore, the proposed system addresses the concerns of both businesses and customers when using cloud-based manufacturing. In the upcoming section, we will discuss blockchain-based cloud manufacturing applications in detail.

A study on blockchain and IoT (Internet of Things) addresses some key challenges [5]. The Internet of Things means the classes of the network-centric system are connected via the internet (not just computers) and are part of a larger system such as a smart city. IoT has great potential, and blockchain is adding value to such a system. Commonly, IoT is in smart cities, smart homes, smart property, the data market, and smart energy, to name a few. Furthermore, the authors point towards issues that will require research and development community attention. The issues include the internet of things and protocols and standards that will govern blockchain and IoT interfaces. IoT-based data generation and processing are learning toward machine economy. It can also lead towards a fully trusted system that is not dependent on the negotiation process. Removing intermediaries and making computer networks and systems secure for smart cities and smart homes is the need of the hour. It also plays an important role in the evolution of smart contracts. IoT-based blockchain will lay the foundation for a breed of smart contracts that will act as a foundation for network-centric systems.

Games area is also studied for games implementation [6]. The study shows that games have some benefits such as transparency, asset ownership, asset reusability, and user-generated content that blockchain technology implementations can most suitably handle. The study shows that most of the games are on Ethereum operating system. Furthermore, the study also shows that blockchain-based gaming will change the gaming landscape and introduce some new research directions such as gaming technologies and resource management, to name a few. The authors emphasized that the current blockchain games offer a promising future, but they are not limited. The authors argue that blockchain games should maintain playfulness and not emphasize the financial element in the game only. However, blockchain-based gaming will help emery new smart contracts.

Blockchain and AI are an emerging trend [7] and are studied for blockchain-based and artificial intelligence-based data science implementations – the major theme of decentralized artificial intelligence work transition. Blockchain-based artificial interline will introduce new filed such as digital twins, explainable artificial intelligence, hybrid learning, and automated machine learning, to name a few. The authors described those new qualities would emerge in artificial intelligence, such as more trust in intelligence products, more data security, high efficiency of data, and improved collective intelligent agents. Explores cited in the work show that blockchain-based artificial intelligence has been implemented in public, consortium-based, and private blockchain platforms. Blockchain-based artificial intelligence has been mostly implemented in Solidity, C++, Java, and Python, to name a few. Blockchain-based artificial intelligence will open new avenues in decentralizing healthcare and connect all stakeholders such as physicians, laboratories, drug manufacturers, medical researchers, and other stakeholders. This trust-based interaction and artificial intelligence will revolutionize. The authors argue that as decentralizing artificial intelligence models improve, enhanced-precision farming technologies will benefit from smart contracts in terms of benefiting from blockchain technology, the output from farms will be enabled with trusted data. Also, ocean exploration technologies will improve with blockchain and deep seabed robot exploration. Furthermore, artificial intelligence and blockchain in the energy sector will transform the industry by improving distributed energy resources, data management, and data collection from various points. Finally, the authors explain that there are issues that require the focus of the research community. That includes privacy, side chains in the block, improvement in the smart contract structure, and blockchain security. Furthermore, the lack of standards in combining blockchain and artificial intelligence will determine the research agenda for a long time.

3 SMART CONTRACTS

In a study about smart contracts [8], authors define a smart contract as "Smart contracts are computer programs that can be consistently executed by a network of mutually distrusting nodes, without the arbitration of a trusted authority." The authors in this survey presented various kinds of smart contracts for Ethereum and bitcoins. The basic idea of this work was to analyze smart contracts, providing a taxonomy of smart contracts, and present design patterns of the smart contract. This work discusses various platforms such as bitcoin, Ethereum, counterparty, Stellar, Monax, Lisk, and associated programming languages. A smart contract is distributed among various financial, notary, game, wallet, library, and unclassified contracts. Most of the smart contracts have been developed in the financial sector and notary sector. The author's described design patterns are token design pattern, authorization design pattern, Oracle design pattern, randomness design pattern, poll design pattern, time constraint design pattern, termination design pattern, fork design pattern, time check design pattern.

In a study about design patterns on smart contracts [9] authors discuss the important design aspects and trends in smart contracts currently available. The authors establish that a combination of law and business rules has given rise to the smart contract. This definition presented by authors shows a need in the industry to develop software for business, which can implement business with trust and certainty under technology supervision, with the least user controls.

In another study about smart contracts [10], the authors establish that smart contracts have a wide spectrum of applications and dynamics, but their implementation must be error-prone and fault-tolerant. It is due to this reason, faults associated with smart contracts have resulted in huge losses. The authors define the layers for research of smart contracts. These layers include the application layer, manifestation layer, intelligence layer, operations layer, contracts layer, and infrastructure layer. The authors further explain that smart contracts implement business logic in the form of if-else statements. These statements are implemented over peer-to-peer blockchain to deliver business value. It is agreed by all parties on blockchain and verified by entities called miners. Furthermore, the authors point towards some potential challenges faced by smart contracts research and development. These challenges include contract venerability, blockchain limitations, privacy issues with smart contracts, and legal issues with smart contracts.

Focusing on the applications of smart contracts in various domains [9], the authors define some major groups for finance, management, the internet of things, and energy. The future trends might include formal verification of smart contracts, issues to handle performance, and logic complexities by a smart contract. One of the key issues discussed by the author is social issues and smart contracts. How will the transition to a blockchain smart contract society occur, and how will research and development for such a platform occur. Some standards must be met for experimentation to explore social issues changes with the implementation of blockchain.

A very comprehensive list of smart contracts programming languages, development frameworks, testing frameworks, and tools for front-end development has been published on the web recently [11]. Most academic publications are not software development tools oriented, so most of the literature lacks a comprehensive picture of the tools. There are frameworks for developing smart contracts such as truffle that provide a comprehensive option to developers. Different languages such as Solidity, C++, and Java are popular for writing smart contract code. Most of the smart contract platform for deploying smart contract is Ethereum. Remix IDE has been gaining popularity in recent times. We will present a detailed list of programming tools for smart contract development for the cloud.

In this section, we covered the introduction and structure of smart contracts. We presented the literature that discussed smart contracts, their applications, design patterns, and issues related to advancing smart contracts. We also cited some work and presented some key technologies developed to implement smart contracts. The next section will present the methods adopted to conduct a systemic literature review of smart contracts. We will also present key trends that have been covered in the smart contract and blockchain systemic literature review.

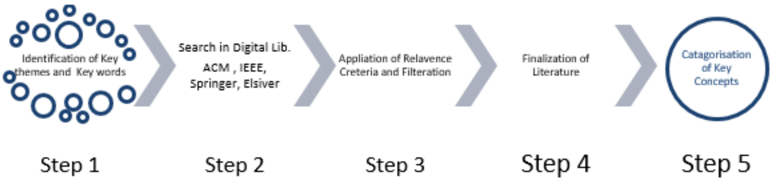

Figure 2. Steps of literature review

RQ1. What are some key architectural approaches blockchain uses for manufacturing?

RQ2. What kinds of smart contracts are available for cloud-based manufacturing?

RQ3. What are some dApps available for cloud-based manufacturing?

RQ4. What are some research issues/software developments related to blockchain application to cloud-based manufacturing?

The following steps were taken to conduct the literature review. The steps are discussed below.

String Used for Search. Strings selected to retrieve data from the digital library/ academic resources were as follows: Smart contract, smart contract + cloud manufacturing + cloud manufacturing blockchain + blockchain.

Sources for Data. For the research articles retrieval, several data sources were explored. The data sources were the Digital Library of ACM (Association for Computing Machinery), the Digital Library of IEEE, Springer, and Elsevier. They were given keywords for the respective.

Information Retrieval. The information extracted from digital libraries was again filtered for relevance and quality. Abstract, methodology finding was given special attention to judging the quality of the articles. Further detailed article review was performed to mark that if the article was highly relevant, moderately or least relevant. The article that was selected was narrowed down.

Raw Search Results.

Inclusion/Exclusion Criteria.

- Only those papers were selected that were published in English.
- The articles that contributed to a prototype/artifact of cloud manufacturing and smart contracts were selected.
- It contained survey papers and proof of concept articles.
- The articles include the algorithms and system environments for smart contracts.

Search String	**Number of Articles/Search Results**			
	ACM	**IEEE**	**Springer**	**Elsevier**
Smart Contract, Blockchain	100 860	1 542	7 505	2 570
Smart Contract + Cloud manufacturing	164 751	10	15 479	6 293
Cloud Manufacturing Blockchain	90 385	35	10 198	4 228
Blockchain + Cloud Manufacturing	90 385	35	10 198	4 228

Table 1. First search string

Source	ACM	IEEE	Springer	Elsevier
Number of Articles	20	30	22	11

Table 2. Second search

4 RESULTS

We will address the research questions stated in the previous section. They are as follows.

RQ1. What are some key architectural approaches blockchain uses for manufacturing? Blockchain has been implemented in the manufacturing industry. Blockchain implementation is a collective structure of dApps, smart contracts, and the environment (Ethereum).

Table 5 shows that blockchain-based cloud manufacturing is gaining momentum. The specialized smart contracts and trust-oriented manufacturing are what were needed to synergize cloud and smart manufacturing industries – the blockchain-based cloud manufacturing industry. When we look at the bigger picture, we deduce that blockchain will eventually become an integral part of smart factories. We conclude that blockchain-based solutions should be experimented with vertically and horizontally for cloud-based manufacturing and beyond. Further, it can act as a step towards a reconfigurable step towards factories that will eventually provide an opportunity for manufacturing that can even be backed with artificial internet backbones. Moreover, open-source, Ethereum-based solutions and experimentation can help us maintain a pace towards the goal.

Source	ACM	IEEE	Springer	Elsevier
Number of Articles	7	20	10	8

Table 3. Third search

Source	ACM	IEEE	Springer	Elsevier
Number of Articles	3	13	3	4

Table 4. Final articles selected

RQ2. What kinds of smart contracts are available for cloud-based manufacturing? This section discusses smart contracts and their implications on the cloud-based manufacturing industry. Most of the work has been done in the latter part of this decade. The overview of smart contracts helps us to identify key techniques and procedures to implement smart contracts. Moreover, the work also helps us understand the challenges and limitations associated with the implementation of smart contracts. The following tables present some key work done in smart contracts, including a survey of smart contracts and some work in smart contracts directly implemented on cloud-based smart contracts.

Smart contracts for blockchain are showing encouraging trends for cloud-based manufacturing. The main overview of smart contracts in Table 6 shows a need for a more powerful and expressive programming language for smart contract programming. Further, these surveys show that although there are blockchain solutions for cloud manufacturing, the research community has shown that interests are advancing smart contracts based on the internet of things (IoT) based systems, cloud computing, and smart manufacturing. The min interest smart contracts have been product lifecycle management. Different design patterns are needed for cloud-based manufacturing for the development of blockchain-based manufacturing.

The overview in Table 7 shows us that smart contracts development has focused on service violation, time commitment, and trust establishment during purchase and negotiation on cloud market for market items. The applications show us that most of the applications are Ethereum based development. Most of the smart contracts that have been discussed in the overview are bits and pieces of the overall cloud-based manufacturing domain, and there seems an emerging application rather than a framework-oriented approach towards the smart contract's development. Furthermore, there is also a need for software best practices that should be developed for could-based smart contract development as the implementation of smart contracts in cloud-based manufacturing can potentially be applied to avoid a wide spectrum of risk to the production line and risk by the participating parties. Solidity and Ethereum emerge as major development platforms and languages for cloud-based manufacturing.

RQ3. What are some dApps available for cloud-based manufacturing? dApps are distributed applications that are developed on the top of the blockchain stack. They act as interfaces and package for the one or multiple smart contracts deployed for the blockchains.

There are very few examples where smart industrial manufacturing has taken full advantage of the blockchain ecosystem. dApps form the blockchain's overall

Reference	Theme of Work	Architectural Approach	Key Elements of Architecture Outcome and Impact
[12]	Sharing of manufacturing information on the blockchain. The work (Fabrec) connects computer and Raspberry Pi-based nodes.	Ethereum based decentralized four computer node prototype implementation.	3 Smart contracts were developed for the implementation, such as GRC, PHEC, and PRC Implementation of blockchain-based transaction/information for manufacturing processes
[13]	A system that facilitates the combination and usage of multi-source heterogeneous data for product lifecycle management. The work presents a five-layer framework for product lifecycle management.	Hyperledger Fabric-based implementation and Amazon web services-based cloud setup. The system implements co-creation, product tracking, maintenance, and regulated recycling.	Implementation of cloud-based manufacturing using blockchain. In the beginning, during, and end of life, the product uses design data on-chain and design data access.
[14]	Blockchain-based trust mechanism establishment for small and medium enterprises for manufacturing. The work aims at issues with "trust tax".	Survey/Discussion	Emphasis on Trusted Manufacturing Process with IoT Cloud-based manufacturing is a trusted platform
[15]	Creation of "trust factories" in the blockchain-based manufacturing era. Survey /Discussion	Emphasis on Trusted Manufacturing Process with IoT	Cloud-based manufacturing is a trusted platform

Table 5. Blockchain-based studies for manufacturing processes

structure and body, including the system's front end and back end. dApps engineering and structural aspects indicate that these apps can easily integrate with the existing cloud-based platform due to web orientation (see Table 8).

RQ4. What are some research issues/software development related to blockchain application to cloud-based manufacturing? The literature on smart programming contracts and cloud-based manufacturing are mostly based on Ethereum based development done in Solidity programing language. A comprehensive industrial report has been published [11]. The report's main extracts that show the software development (experimentation design tools) are discussed

Reference	**Purpose of Survey**	**Impact on Understanding Smart Contracts**	**Key Benefits for Cloud-based Smart contract**
[16]	To survey tools analyzing smart contracts across various domains	Smart Contracts need to be processed for Code analysis with the need for code transformation	The work establishes key benefits of solidity programing language and Ethereum virtual machine
[17]	To study Safer Smart Contracts	The work establishes a deeper understanding of the programming languages involved and the pros and cons of each tool to develop these smart contracts. The study covers verification techniques and the costs associated with them.	The work can enable developers to choose programming languages and verifications methods for cloud-based programming.
[18]	Smart contracts systemic mapping	The work establishes an understanding of key issues related to smart contracts	Programing smart contracts is one of the key challenges identified by a smart contract.
[19]	To study Smart Contracts for the internet of things (IoT)	The work discusses the deployment consideration of smart contracts in an IoT environment	IoT-based smart contracts facilitate understanding of cloud-based manufacturing smart contracts deployment.
[10]	Smart Contract Survey	The work discusses the basic structure and working of smart contracts	Smart contracts deployed in finance and management help us follow best practices for cloud manufacturing smart contracts.
[20]	Transition to decentralized cloud computing and smart contract's role	The work discusses the possibilities of smart contract role in enabling pervasive IoT applications	Ethereum based smart contracts form a major opinion in cloud-centric blockchain application
[21]	To survey cloud	The work focuses on developing a reputation system	Cloud manufacturing extended to the cloud market can benefit from the work.
[22]]	Survey on Smart Contracts	The work discusses lifecycle challenges on smart contract	smart-contract lifecycle management on cloud manufacturing platforms can benefit from the work
[23]	Survey on Blockchain and Fog solution	The work analyzed Golem, iExec, and SONM	Smart Contracts need substantial standardization from the cloud to be successfully delivering services.

Table 6. An overview of key survey conducted in smart contracts

Re-fe-ren-ce	**Purpose of Smart Contract**	**Type of Smart Contract**	**Key Benefits**	**Key Architectural Approach's**
[24]	This work presents a Virtual Market Place	Static (Non-negotiable smart contract	Purchases of virtual services on a cloud computing platform	Solidity language – J.P. Morgan blockchain – Saranyu REST API
[25]	Auction and Trade Framework	Time commitment Scheme	Trusted Auction/bidding process	Solidity Language Ethereum Deployment to network Rinkeby
[26]	Negotiation on the cloud marketplace	Bazar Contract	Three versions of Bazar Contract such as simple, storage only, and lightweight	Solidity Language Ethereum Remix IDE Storage network IPFS
[27]	Smart contract for detecting and reporting service violations	Witness Model	The work enables trustable cloud operations by introducing fairness, verification, and proof of violations	Ethereum blockchain, Rinkeby. Solidity language
[28]	dApps for Supply chain management	Virtual Operation	Blockchain-enabled cyber supply chain system	BPMN (Business Process Model and Notation, Python Language
[29]	Smart Contract M2M electricity market in the chemical industry via the IoT	Producer-Consumer	Purchase of services over the cloud	Multichain package Windows OS Aspen Plus
[30]	IoT cloud delegation	Stack4Things IoTronic delegation	Resource Authorization and delegation	Ethereum based, Solidity Programed, Remix IDE for development

Table 7. An overview of cloud-based smart contracts

Reference	Purpose of dApps	Contributions of the Work	Potential Benefits Related to Cloud-Based Manufacturing
[31]	Introduction to dApps	• Types of dApps • Popular categories of dApps • Cost and Deployment of dApps with smart Contracts	• dApps for cloud-based manufacturing are almost non-existing • Most work in dApps consists of one smart contract

Table 8. dApps and cloud operations

Reference	Purpose of the Study	Challenges Identified for Industry 4.0	Limitations
[32]	• Cyber-Physical Production Systems • Data Analytics • Augmented and Virtual Reality • Robotics • 3-D Printing	• Interoperability standards • Management of Multichain • Regulatory and legal issues • Infrastructure	• Scalability • Consensus Algorithm • Energy Needs

Table 9. Smart 4.0/smart city, blockchain and cloud manufacturing challenges and limitation

in Table 10. Languages include Solidity, Flint, Vyper. Frameworks include Truffle, Integrated Development Environment (IDE) include Parasol, Visual Studio, Remix Platform include Ethereum, Hyperledger and Paradigm/Style of Programming includes Contract-Oriented Programing Imperative Programming Object-Oriented Programming. In addition to Table 10, there are more of these tools. dApps tools and smart contract testing tools, security enhancement, and implementation tools develop a complete development suite. Table 10 shows a snapshot of a researcher and developer aiming to develop cloud-based manufacturing experiments supported by smart contracts.

Element of Application Development Stack				
Language	**Frameworks**	**Integrated Development Environment (IDE)**	**Platform**	**Paradigm/Style of Programming**
Solidity	Truffle	Parasol	Ethereum	Contract-Oriented Programming
Flint	–	Visual Studio	Hyperledger	Imperative Programming
Vyper	–	Remix	–	Object-Oriented Programming

Table 10. Language, framework, IDE, platform, paradigm

5 DISCUSSION

There are numerous opportunities in literature for software engineers to work in smart contracts for cloud-based manufacturing. Some of them are discussed in the following. There is much work for requirements engineering-related topics for the work. Since blockchain-based cloud manufacturing is evolving, it is imperative to develop requirement engineering techniques for such assets; currently, computer science engineering methodologies are being used to develop system-level techniques. For software requirements engineering for blockchain-based cloud systems, it must be a mixture of distributed and centralized computing paradigm. Furthermore, the more risk-averse approach must be adopted to develop requirements engineering documents.

Human resource management will transform with the advancement and application of blockchain systems. The main idea of the blockchain-based cloud-based manufacturing era is that there will be comparative advantages and disadvantages of machine-driven trust compared to trust provided by humans – furthermore, the studies in societies where corruption is rampant and industries in crisis due to corruption. There will be an interesting outcome on how the blockchain-based manufacturing system will revive sick industries.

Such case guides will be more important when implemented in societies and economies where corruption has been destroyed. Furthermore, smart contracts in such implementation can lead to a new breed of algorithms that become standard practices. Design tools in CAD/CAM Computer-aided design and manufacturing is an important aspect of computerized designing. The trusting manufacturing process involves transitioning the product from design to final shape according to the planning. Most of the time, deviation and issues with various stakeholders cause the final product to suffer. Blockchain-based trusted manufacturing enables the development of end-to-end products with features that can help us tackle this issue.

There are challenges for software engineers in smart contracts-related literature. Some of them are discussed in the following section – few prototypes. Very few prototypes have shown the effects and impact of blockchain-based cloud-based manufacturing. Furthermore, smart contracts and dApps are even rare to help such kinds of situations. Furthermore, there has been an evolving trend to develop prototypes that involve hardware (IoT) platforms. So, it is imperative to develop a prototype that can work on a wide range of experiments. Less practical information (industry-oriented) research articles often are more academic-oriented and cover less detail on how things are done in the industry. Languages and tools, environments, and platforms are often not open sources, therefore hindering reimplementing solutions. Few open-source implementations are showed. However, most of the case studies reports are on the Ethereum platform and development in Solidity language. We must consider that there is ever demand end-to-end opensource platforms implementation, including hardware, when IoT-based integrated blockchain-based smart manufacturing process case studies are developed. Furthermore, there is still growing demand for blockchain, and the industry is yet to capitalize on its full potential; there is a need for more proof-of-concept type opensource applications.

Major limitations in work are discussed as follows. Most work on Ethereum, and less work on Hyperledger and other platforms as Ethereum based design and Solidity will be developers' main tools of choice. However, there are limitations for software engineers. It could become a bottleneck in the long term as only Ethereum based capabilities will surface in the software engineering circles. Further, one specific platform and a specific language offer some generic and some specific capabilities. Therefore, this approach can limit the engineering designing approach and limited portions of software developers. Very few industrialized nations lead cloud manufacturing, and therefore, there is a need for frameworks that support the development of smart contracts with taxonomies and approaches. Our attempt to structure the smart contract development view that smart contract will continue to evolve to a smart contract framework development.

Second, the opinion and standards are evolving for smart contract development for cloud-based manufacturing. Protocols are evolving for cloud and smart contract deployment for manufacturing. Since cloud programming practices with blockchain technology are not very common, it is imperative to know that there is a need to develop unified frameworks for cloud-based software development with blockchain smart contracts integration frameworks.

6 CONCLUSION AND FUTURE RESEARCH DIRECTION

This literature review concludes that smart contract development is the future for the cloud-based manufacturing domain. We answered the four research questions about the development of smart contracts and cloud-based manufacturing. The conclusion of the work is presented as follows.

RQ1. What are some key architectural approaches blockchain uses for manufacturing? The trusted manufacturing process will become a reality for the next couple of years. The main idea for understanding blockchain-based manufacturing is that there is a higher level of chances that IoT-based systems and blockchain-based systems implementation will rise together with smart contracts dependent on blockchain and IoT systems. Therefore, we conclude that there is no clear winner in Ethereum or Hyperledger based architectural approaches for blockchain for cloud-based manufacturing.

RQ2. What kinds of smart contracts are available for cloud-based manufacturing? Most smart contracts are surveyed, and they cover all domains where smart contract-driven blockchain solutions are implemented. Specifically, for cloud-based manufacturing, the main role of the smart contract is to automate a business and legal process, without human intervention, to an effective, safer, trusted, and faster method. These benefits of the smart contract will make cloud-based manufacturing transition to a next-generation smart industries domain. Furthermore, the idea of virtual operation and e-commerce will change because of the smart contract based on blockchain and among various stakeholders such as employees, traders, suppliers, and manufacturing units owners. Such manufacturing processes' inherent transparency and audibility can revive low-performing and smart contract-based new work contracts. Although there are still bossiness and legal hurdles in smart contract deployment, the current proof of concept have changed the manufacturing landscape.

RQ3. What are some dApps available for cloud-based manufacturing? dApp is still in its infancy in the cloud-based manufacturing domain. There is huge potential to develop cross-industrial and international level integration of manufacturing processes, leading to dApps that integrate the manufacturing processes. Further, robotic manufacturing and cyber-physical systems have led to the proof of concept in dApps and smart manufacturing process advancement.

RQ4. What are some research issues/software development related to blockchain application to cloud-based manufacturing? Most of the experimental platforms chosen to develop the proof of concept for blockchain-based smart contracts are Ethereum and Solidity. The integrated development environment and target platform did not prove important in developing smart contracts. Similar open-source hardware such as Arduino and Raspberry Pi have become the choice platform for researchers. Furthermore, in the future, there are vast opportunities for context-aware smart contract development for cloud-based computing. Context-awareness has proven to be an important platform for the development of smart factories and smart cities. In addition, smart contracts for cloud-based manufacturing can enhance understanding of pervasive and ubiquitous computing.

Conflict of Interest Statement

The corresponding author states that there is no conflict of interest.

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