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Blockchains: A conceptual assessment from a product lifecycle implementation perspective

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Abstract.

PLM systems are heavily distributed collaborative platforms resulting in multiple challenges related to the integrity and reliability of the exchanged information. Such issues are usually difficult to address using traditional software solutions. However, since the introduction of blockchains, such challenges are currently being effectively addressed. On the one hand, traditional PLM systems design philosophy was mainly about centralized proprietary systems that have difficulty to cope with new distributed and open environments imposed by the extensive use of IoT platforms and other Industry 4.0 tools. On the other hand, blockchains address data integrity issues by design, and mitigate some of the trust concerns found in collaborative platforms. Through this paper, we study and evaluate the integration of blockchain technology with PLM systems highlighting the different advantages, challenges, and issues that this integration might induce.

Keywords: Product Lifecycle Management, Blockchain, Supply Chain Management,

1 Introduction

PLM systems are the swiss knives behind product manufacturing. Their original design philosophy was to integrate all the processes related to the product lifecycle into a single centralized solution. This promised a lot of improvements to all product lifecycle stages and attracted a lot of interest. By nowadays standards, product information is distributed across multiple stakeholders and traditional PLM systems have a hard time coping with Industry 4.0 standards which stress on openness, the use of cyber-physical systems, IoT, AI, cloud-based solutions, etc.[1]. Usually, companies are often not ready for this transition as it may alter with their business logic and can result in major failures in their security policies. In fact, having their intellectual property (IP) in cloud environments can lead to it being compromised and stolen. However, it is really difficult to avoid these transformations especially in a time where companies have to manage in-

formation across multiple remote sites or to deal with multiple international stakeholders such as suppliers, etc. The vulnerabilities of traditional systems and the constant need to shift to Industry 4.0 processes are pushing for finding new ways to secure PLM systems while enabling new processes paradigms [2, 3].

These applications among others demonstrate the potential of blockchain technology is revolutionizing the way we collaborate. As a result, through this paper, we aim at studying the PLM-Blockchain integration while evaluating its added benefits, potential drawback, added value and challenges yet to be addressed.

The rest of this paper is organized as follows. In section two, we give a general overview of PLM systems. This is followed in section 3 by a series of selected questions that we elaborated to shape the integration of PLM and blockchain. In section 4 we present supply ledger which is a new project aiming at integrating the blockchain technology in the context of supply chains. Our conclusions and final thoughts are depicted in section 5.

2 Product Lifecycle Management Systems

PLM systems encompass a set of business software tools used in an enterprise context to manage the entire lifecycle and activities related to products and assets from their design, manufacturing, iterations until it is discontinued and disposed of. The goal of such systems in the design phase for instance is to empower the efficiency of product design by accelerating the processes, improving the communication between the different actors, reducing costs, and allowing for effective iterative design [4]. One of the main PLM systems' features is the ability to efficiently integrate the data of the different product's stages. Since the rise of the Internet and with increasing performance of information technologies, PLM systems were adapted to involve stakeholders and diverse collaborators in the whole lifecycle process [5] (see Fig. 1). Usually, these stakeholders may be collaborating on different life cycle stages: design, prototyping, testing, validation, manufacturing, distribution, maintenance and recycling. PLM is the go-to tool for companies seeking improvements to their product quality, their collaboration as well as their competitiveness [6].

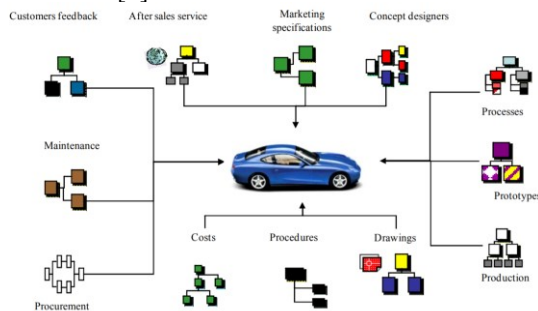


Fig. 1. The Product data managed by PLM systems (a case of care manufacturing) [5]

By nowadays standards, and with Industry 4.0 challenges, several challenges related to security and data integrity have arisen with the introduction of IoT and cloud infrastructures. The blockchain technology and a collaboration infrastructure are good candidates to tackle such challenges.

3 Blockchain in PLM Systems

There is a great deal of complexity associated with data exchanges around PLM systems due to the iterative processes where multiple internal and external stakeholders are involved [7]. Nowadays products are made collaboratively. Think of any product you use, and you will see that it requires the involvement of multiple companies that manufacture a certain part of it. In such a scenario, it is usually the manufacturer or the assembler who is the chief of the orchestra and has to coordinate all the data exchanges between the network of stakeholders. The complexity of such networks grows up exponentially which raises concerns about security, integrity of data, etc.

The blockchain is a decentralized collaboration platform that was proven to solve such concerns. Blockchains have been adapted to multiple applications. To study its adaptation to PLM systems, we have highlighted hereunder a list of points that will help understanding how to integrate blockchain and PLM systems.

3.1 What is a Blockchain?

Blockchain refers to a new evolving collaboration technology that is considered disruptive by many experts. Blockchains are shared ledgers used to log transactions in an append-only fashion (see Fig.2.). These ledgers are usually stored across a decentralized environment. The data that they stored is secured and chained using different cryptographic techniques. Cryptocurrencies are one of the first applications relying fully on the blockchain technology. As awkward as it seems, blockchains are not managed by any third party. In blockchains, there is no space for a regulatory body, or managing authority. Trust is achieved by consensus and by design. Blockchain gained in popularity following the introduction of the bitcoin cryptocurrency in 2008. For cryptocurrencies such as bitcoin, the blockchain contains all the transaction data [8].

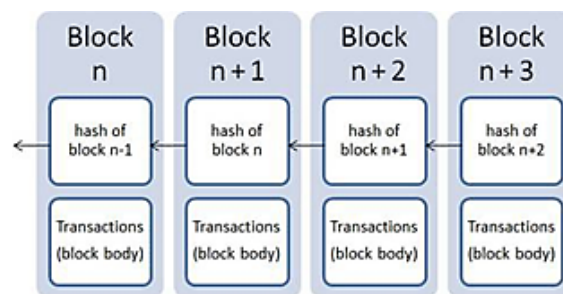


Fig. 2. Blockchain diagram highlighting the hashing of blocks

3.2 How Disruptive is the Blockchain?

The disruption that blockchain made in the tech industry can be comparable to the one made by the internet. It revolutionized the financial industry and its concepts are being adapted to other sectors [9]. The revolutions introduced by the blockchain can be summarized as follows:

- Secure shared tamperproof storage: Data is shared through a decentralized architecture where each node holds a copy. Each block of data is linked to the previous one.
- Consensus Trust: Trust is not achieved by a managing party but rather through a census where a proof-of-work algorithm is used to validate new blocks and transactions (See Fig. 3).
- P2P transactions: no third party is required to certify a transaction or to monitor it.
- Smart contracts: a new way of transactions using the concept of pre-conditions and action. A smart contract is a script that resides in the blockchain and executed upon the satisfaction of a set of pre-conditions. As an example, think of a payment issued once tracking shows delivered, etc. These contracts are enforced automatically without any third party.

Through these concepts, the blockchain-inspired multiple fields such as health care, supply chain, voting, etc. thanks to all the benefits related to transparency in a peer-to-peer network.

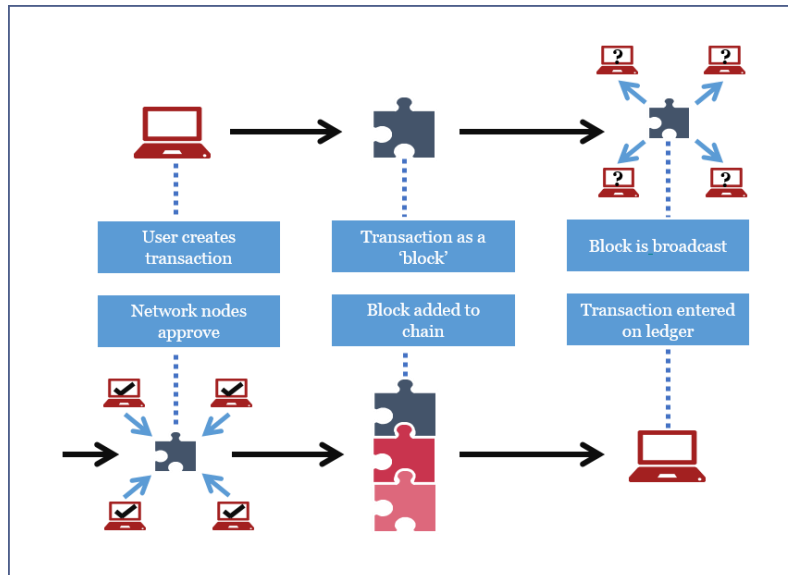


Fig. 3. The consensus in peer-to-peer blockchains¹

¹ <https://digital.pwc.com/en.html>

3.3 What Benefits Does the Blockchain Bring to PLM Systems?

The benefits of the blockchain are linked to its key features. Through these features, the blockchain can bring additional benefits to most collaborative applications including PLM [10]. In the following, we highlight the key features of the blockchain technology and their benefits in the PLM context.

- Decentralized: By nowadays standards and with the massive use of IoT and cloud-based solutions, decentralized architecture can be used to solve issues related to reliability and uptime eliminating points of failures such as servers, etc. Blockchain relies on multiple nodes which can store and handle the data.
- Immutable: Blockchain is an append-only database where data is secured by hash chains and other strong cryptographic concepts. PLM systems can benefit from these concepts in all forms of critical data such as maintenance logs, etc.
- Transparency: depending on the implementation and the targeted application, blockchain can enforce transparency constraints as the data is shared publicly in multiple sources and cannot be tampered with. In PLM systems, this can be useful whenever information needs to be publicly available while being able to verify its authenticity.

3.4 Is the Blockchain Successful in Other Fields Related to PLM Systems?

The blockchain technology which is the backbone of cryptocurrencies did not stop flexing its muscles as one of the most secure and resilient peer-to-peer information exchange platforms. Thanks to their proven advantages such as security, availability, tamper-proofness, etc., blockchains have been adapted to multiple applications in healthcare, supply chains, finance, ... In the supply chain, many blockchain-powered applications are currently being deployed for real-world use especially in the logistics industry. For the logistics supply chain, IBM and Maersk presented the first real-world scenario of using the blockchain as the main data exchange platform to ship a container from Lyon, France to Newark, USA. The challenge, in this case, was not the physical movement of the container itself but rather related to all the documents that are exchanged between the different stakeholders (shipper, banks, customs, carrier port authority, forwarder, etc.). By using blockchain in the scenario, all the information was exchanged using one platform which made it more transparent, effective to track, and added the ability to quickly identify and solve any issues which resulted in a boost in terms of performance.



Fig. 4. The Modum IoT tracking device [11]

The pharmaceutical industry is facing many challenges related to transparency, conformity, and reliability of pharma products. The blockchain start-up Modum [11] is working on ensuring drug and medical product safety with blockchain technology. Their product 'Mod' (see Fig. 4), which is an IoT sensor, is revolutionizing asset tracking. The 'Mod' device is added by the shipper or the pharmaceutical factory to packages of pharmaceutical and medical products prior to their shipment. During the transportation of the package, the device monitors the temperature and the humidity conditions of the package autonomously. When the receiver, a pharmacist, for instance, accepts the package, all the data is transferred to the blockchain where a smart contract is executed to check if the product always complied with the temperature and humidity regulations. Once in the blockchain, this data can't be changed and is publicly accessible. The result is immediately reported back to the end consumer as well as to the distributor. This tool is currently in use in many European countries as new GDP regulations (European commission Good Manufacturing and Distribution Practices) require the reporting of temperature deviation and humidity levels to both the distributor and the recipient of the medical product.

3.5 How Can Blockchain Be Applied in PLM Systems?

In the context of industrial applications beyond the fintech context, Internet of Things (IoT) seems to be the most targeted application for the huge amount of interaction between sensors and edge devices with the cloud. This imposes challenges related to infrastructure reliability, security, and data integrity. In this context, a blockchain-based IoT platform was presented in [12], the authors presented a proof-of-concept of a sensor network in an industrial application interacting in a trustless environment through the blockchain. The authors of [13] investigate how to implement an open manufacturing architecture through a cross-enterprise service and knowledge exchange framework based on edge computing and blockchain. In the same context, in [10], a blockchain-based business management framework is presented. The authors highlighted the fact that Business Process Management (BPM) is one of the pillars of Industry 4.0 and one of the critical bottlenecks to proceed with BPM systems is related to data integrity. The proposed solution is based on the blockchain technology and aims at addressing the highlighted issues. Another application presented in [14] targets the challenge of securing smart grids through the design and implementation of a blockchain securing machine-to-machine interactions in the context of electricity trading.

In the supply chain management context, numerous applications were proposed such as [15] where the authors proposed a conceptual model to integrate the blockchain technology with supply chains. The authors of [16] explored the use of ontologies and a design tool for blockchain-based supply chains where they translated some traceability representation from an ontology to smart contracts to enforce constraints. An aircraft parts supply chain case was studied in [17] where a blockchain is used not just for traceability but also for performance monitoring and parts usage which positively impacts data integrity and safety. An architectural design scenario of industrial platforms

based on blockchain-powered product-centric information management platform using the blockchain technology was presented in [18].

The following table represented a set of industrial application based on the blockchain. We highlight the type of blockchain used and the benefit of integration in each type.

Table 1. A table of some blockchain-based industrial applications highlighting the benefit of blockchain use in each case.

Industry	Type of Blockchain[19]	Benefits of using blockchain	References
Supply Chain Management	Private or Consortium	<ul style="list-style-type: none"> • Help reduce time delays, management costs, and human errors • Facilitate faster and more efficient agreements between companies involved in logistics activities. • Securely and efficiently support planning, scheduling, coordinating, monitoring, and validating logistics activities 	[20, 21]
Real Estate	Public or Consortium	<ul style="list-style-type: none"> • Transparency and real estate data accessibility • Reduced transfer/transaction costs • Tokenization of properties, a piece of real estate can be a stock holding • Technical efficiency and reduced red tape 	[22, 23]
Financial Settlement	Public or Consortium	<ul style="list-style-type: none"> • Reduce financial activities costs • Reduce transactional and operational errors • Enable the use of digital currencies • Enhance insurance policies and related activities such as negotiations, agreements and claims handling • Enable stock exchanges without involving a third party • Enable financial settlements without involving a third party 	[24, 25]
Healthcare	Consortium	<ul style="list-style-type: none"> • Enable controlled sharing of EMRs among multiple healthcare providers and related industries • Facilitate patients' ownership of their EMRs, while inhibiting their ability to alter them • Allow patients to control and securely share their health data while maintaining their privacy. • Enhance pharmaceutical supply chain management processes. • Facilitate fine grain analysis of patients' data, medical innovations and research results 	[26, 27]
Insurance	Private or Consortium	<ul style="list-style-type: none"> • Efficient claims handling • Promotes reinsurance practices 	[28, 29]

		<ul style="list-style-type: none"> • Enhanced KYC (Know your customer) and AML (anti-money laundering) procedures • Enabling insurance on any asset <ul style="list-style-type: none"> • Settle transactions automatically by reducing human intervention 	
Stock Trading	Consortium	<ul style="list-style-type: none"> • Speed up the settlement of trades • Reduce the time taken by intermediaries, operational trade clearance, and regulatory processes • Tracing ownership and automatic dividend sharing 	[24, 30]
Intellectual Property	Public or Consortium	<ul style="list-style-type: none"> • Easy licensing and signature process • Enhance the sharing and transfers of IP • Direct royalties and reduced intermediaries • Digital rights management 	[31, 32]

Despite the appealing advantages that blockchain promises in PLM environments, several challenges are still present to achieve good integration. Most of these challenges are usually not standard as every company has with one or more of the following issues:

- Resistance to change: the stakeholder of a certain platform may refuse to use a blockchain based solution.
- Information security: making the data for public use may lead to leaks if the solution is not designed correctly.
- Potential impact: In the best-case scenario, the integration of the blockchain may boost the performance and secure the data exchanges which can be the opposite if the risks of misintegration are not handled correctly.
- Regulations: Blockchain can be restricted for public use in some countries for financial or non-financial applications.

Overall, any integration of blockchain and PLM systems needs to be evaluated and its performance should be monitored to ensure that this integration is solving problems, not creating new ones. This may be achieved using a set of Key Performance Indicators (KPIs) and performance indicators evaluated upon the testing stage of such platform integration.

3.6 What Information to Put on the Blockchain and How?

Blockchain is an append-only database that is heavily secured using hash chaining and other cryptographic concepts. Blockchain was designed for many things and interaction performance is not one of them. This can be seen as a potential drawback as if one wants to put a large file on the blockchain, this may result in a very important computational burden that can lead to platform failure. Blockchains are not storage platforms, blockchains are not fast interaction relational databases that are used for information retrieval and online queries. Instead, blockchains can be considered as a secure interaction platform that can be used to exchange critical data securely.

Having this in mind, we need to evaluate concretely what to store on the blockchain in the case of PLM systems. Additionally, to ensure that the information is available

for all stakeholders without compromising confidentiality on Intellectual Property (IP), what are the data encapsulation solutions can we use to enforce these rules?

Blockchain provides the stakeholders with an open platform, tamper-proof traceability data, regulatory-compliance checking, etc. However, there are 3 different types of implementation (See Fig. 5): fully public, private and consortium (hybrid). The security and performance aspects vary with each type which makes architecture choices not trivial.

Property	Public blockchain	Consortium blockchain	Private blockchain
Consensus determination	All miners	Selected set of nodes	One organization
Read permission	Public	Could be public or restricted	Could be public or restricted
Immutability	Nearly impossible to tamper	Could be tampered	Could be tampered
Efficiency	Low	High	High
Centralized	No	Partial	Yes
Consensus process	Permissionless	Permissioned	Permissioned

Fig. 5. Type of blockchain depending on their property [18]

In private blockchains, we can select a group of users from an institution or organization to view and/or edit data. This makes it easy to tamper with the data depending on the implementation as the blockchain will be mostly managed by a single entity and can only be used inside an organization. Public blockchains such as the one used by cryptocurrencies, allow everyone to view and access the data. They are more secure, however, their performance low as usually the validation of transaction takes a considerable amount of computational resources. In hybrid blockchains, some peers can see all the data while others can see only selections; or all can see all the data, but only some can add new data. It depends on how it is defined by the system designer.

4 The SupplyLedger Project Approach to Blockchain Integration

Traditional business process management systems rely on the client/server centralized architecture. Several issues arise in these kinds of systems such as downtime, lack of transparency and security flaws. Even though business risk management strategies can address these issues, however, that comes usually with a set of compromises. In the context of Supply Chain management, businesses rely on mutual trust and own ledgers to track and manage their exchanged assets. Nowadays, blockchain technology is proliferating into every field that uses record-keeping and assets exchange. Several companies and researchers are trying to convince businesses to adopt this decentralized approach and show its benefits. Its new features are considered as a revolution in business management to generate value and revenue. However, in reality, it is really hard to make a revolution in something that was established for decades [33].

In an effort to secure supply chain networks, in light with the recent international events and challenges, the blockchain has been successfully used in many fields. In the

context of supply chains and PLM, SupplyLedger is a new project that aims at integrating the blockchain technology with supply chain frameworks.

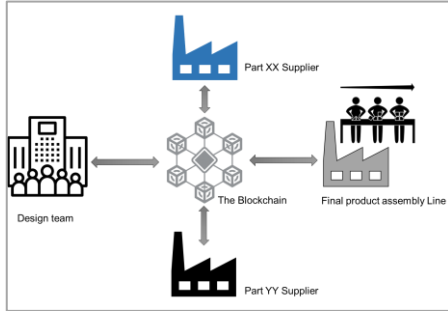


Fig. 6. A blockchain linking a manufacturing supply chain

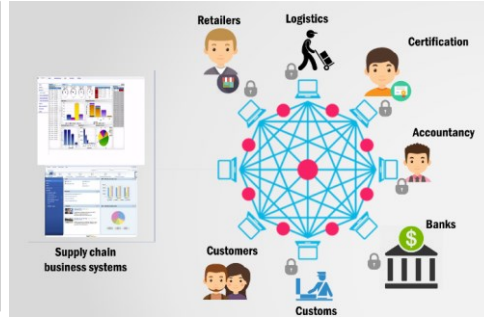


Fig. 7. Blockchain-based/SC interoperability

To improve the business process of Supply Chain management and to leverage the benefits of the blockchain technology, the blockchain should be able to integrate with numerous business systems such as Customer Relationship Management (CRM), Enterprise Resource Planning (ERP), etc. (See Fig. 6 and 7). The benefits of integrating these systems with the blockchain are: transparency, improved reporting, and tracking cost reduction [34]. More specifically the benefits include:

- The blockchain makes the transactions generated by these systems transparent and reliable.
- Integration with the blockchain reduces the costs incurred by disputes on invoices and other transactions between the different parties in the Supply Chain.
- The blockchain stores a copy of the information generated by the different activities in the Supply Chain (tracking, shipping products, etc.) that is tamper-proof and can be referred to at any time.
- Integration with the blockchain provides better transparency in terms of the origin and the current possession of the product.
- The blockchain may improve the tracking of faulty parts that can affect an entire assembly line.

The SupplyLedger team aims at designing and implementing a blockchain-based architecture for supply chain management. The project team is studying existing Supply Chain Management platforms and identifying the functional and nonfunctional requirements captured from end-users focusing on a specific case study. The main focus points are as follows:

- Development of design principles for transforming an existing supply chain model to a smart contract-based blockchain model.
- Interoperability of blockchain-based supply chain management platform with traditional platforms

- Implementation and evaluation of the performance of the proposed blockchain-based system for supply chains
- Mining supply chain data in blockchain architectures.

Figure 8 outlines the architecture of SupplyLedger.

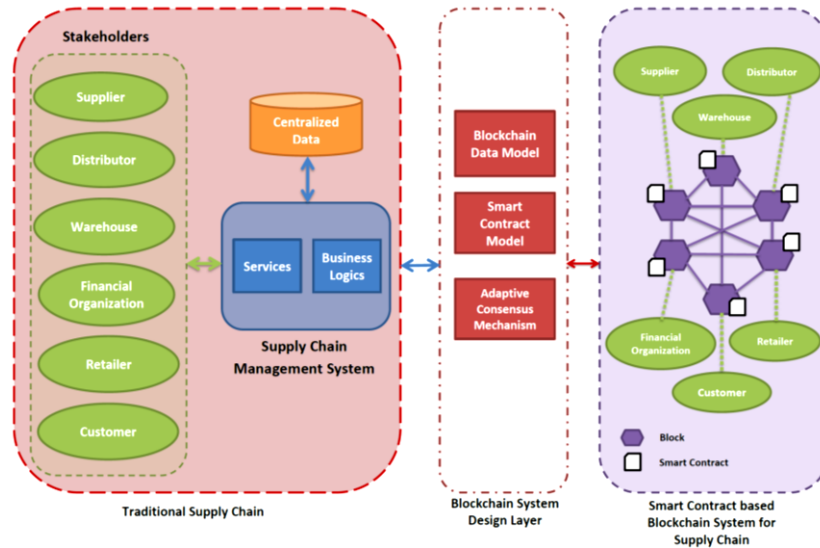


Fig. 8. SupplyLedger architecture

SupplyLedger is an impact-driven project that aims at making a significant contribution towards meeting the Qatari strategic vision of creating a sustainable “Smart Nation” in which its economic sector’s knowledge is promoted and shared securely, safely and transparently through a blockchain-based logistics SC management architecture. The project impact will be achieved through a number of enabling factors that will be realized through:

- Creation of innovative techniques and effective methods for understanding the impact of the blockchain on supply chain management in Qatar. The global objective of SupplyLedger is to specify and develop a blockchain-based solution adapted to the logistics SC management activities.
- The system to develop in the course of the SupplyLedger project will enable a blockchain-based solution that ensures trust, transparency, and security in SCs in Qatar. The goods entering and transiting through the country will be fully annotated with their lifecycle information starting from their origin. This will drastically improve consumer satisfaction not only in the industry sector but also in the community as a whole. The time and cost will also be optimized especially in case of disputes or irregularities as all the information regarding the payment transaction and its physical location are publicly and transparently available on the blockchain in real-time. Refunds will be issued immediately, and products will be delivered securely. Furthermore, counterfeiting will be effectively reduced.

- The SupplyLedger project will provide training for researchers in Qatar higher education institutions such as universities and research centers. This will further enhance the Qatari researchers' understanding of blockchain adaptation to other domains besides the classical financial technologies (Fintech) domain. Thereby allowing them to reap the benefits of the blockchain architecture. Moreover, the project will develop new blockchain business and enterprise integration techniques. This will enable interested stakeholders in Qatar to adopt the blockchain technology.

5 Conclusion

Blockchain is a new innovative way of collaboration that went beyond its original application in cryptocurrencies to disrupt multiple fields. PLM systems are collaborative platforms that manage a wide variety of resources. New industry 4.0 requires new ways of interaction with the abundance of sensor data coming from IoT devices and new ways of collaboration through cloud computing. This induces multiple challenges related to reliability, security and data integrity which can be addressed using blockchain technology. Blockchains address data integrity issues by design and mitigate some of the trust concerns found in collaborative platforms. In this regard, we studied how we can integrate the blockchain technology with PLM systems through a series of selected questions that we elaborated to shape the integration of PLM and blockchain. Additionally, we presented SupplyLedger which is a new project aiming at integrating the blockchain technology with supply chain management systems.

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