Aalto University
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BLOCKCHAIN TECHNOLOGY AND ITS POTENTIAL IN ERP PROCESSES

What is blockchain technology and how can it benefit enterprise resource planning processes?

Bachelor's Thesis
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Abstract of bachelor's thesis

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Abstract

In the last ten years, blockchain technology has transformed from just a digital currency system to supporting complex smart contracts and arbitrary use cases in business. Public blockchains have paved the way for decentralized, tamper-resistant, and transparent systems, offering a solution for the single point of failure found in centralized enterprise systems today. With a literature review conducted on blockchain, enterprise resource planning systems, and their collective usage, this thesis aims to familiarize the reader with the technology and explores the most potential use cases of blockchain in regular enterprise resource planning functions.

This thesis identified supply chain management and accounting processes as the most viable applications of blockchain technology within the context of ERP systems. Furthermore, permissioned blockchains have demonstrated better suitability for enterprise use due to their relative efficiency and closed environment compared to public blockchains. The reviewed literature also emphasized the significance of smart contract functionalities creating possibilities of automation and enhanced process efficiency, as well as presented decentralized access controls as a way to prevent unauthorized access to the ERP data.

Keywords blockchain, enterprise resource planning, erp

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1 Introduction

Blockchain technology was first implemented as a digital cash system Bitcoin (Dinh et al., 2018). While bitcoin was not the first digital cash system presented at the time, it had a mechanism to prevent double spending, a problem which was present with all the preceding systems (Nakamoto, 2008). This system demonstrated the potential of blockchain technology as anyone could conduct transactions and participate in the validation process of the network, without needing to trust any third party in the process.

Since then, blockchain has develop to host smart contracts and its potential in business context has been researched to an increasing extent. Enterprise resource planning systems are one of the central components of modern enterprise operations (Aslam et al., 2021) as they gather processes such as supply chain management, accounting, finance, and customer relationship management (Mundra & Prakash, 2022). These systems pose numerous benefits to organizations, such as standardized and automated processes, and consistent data with a single integrated database (Kitsantas, 2022; Mundra & Prakash, 2022). However, there are certain disadvantages and risks with current ERPs due to their centralized architecture. The risks can be caused either by an internal or external actor of the enterprise, and they can further be purely technical or caused by a malicious intent (Moalagh & Ghadi, 2022). In addition, current ERP systems have been found insufficient in communication capabilities with other systems (Banerjee, 2018).

Blockchain architecture has been proposed to eliminate the risks caused by the centralized approach. Besides making ERP system data transparent for enhanced efficiency while at the same time making it immutable to prevent misdemeanour, the decentralized platform can streamline communication and enable trust between an enterprise and its stakeholders. Permissioned blockchains have been proposed as a suitable option for enterprise use, as they present better efficiency and data security than public blockchains (Dinh et al., 2018). Most often, blockchain consortiums, including only relevant members in the application domain, are considered to yield most benefits (Haddara et al., 2021).

Blockchain integration with ERP system could bring several advantages, particularly in supply chain management and accounting processes of enterprises (Banerjee, 2018; Dai & Vasarhelyi, 2021). The advantages, mainly through blockchain characteristics of traceability, decentralization, and immutability, will be reviewed in the ERP processes that the literature highlights as benefiting the most.

1.1 Research objectives and research questions

The objective of this thesis is to discover how blockchain technology could benefit enterprise resource planning systems. This is achieved with a literature review on both blockchain technology and ERP systems, followed by reviewing articles on the combined utilization of the two technologies.

The research questions are as follows:

1. What is blockchain technology and what are its advantages?
2. What are enterprise resource planning systems are what are their advantages?
3. What advantages does blockchain offer in different ERP functions?

1.2 Scope of research

This thesis examines blockchain technology and enterprise resource planning systems in a holistic way. We review the principles and technological components of both and take a closer look into public and permissioned blockchains since distinguishing between the two is essential when assessing the relevance in the business context. Smart contracts are also reviewed, being an important part of blockchain technology.

In addition, this study focuses on the advantages of the technologies and their combined use. Organizational and legal factors are outside of the scope of this thesis.

1.3 Research methodology

Recent and highly relevant research articles and papers were used for the literature review of this thesis. Scientific reference databases Scopus and Web of Science were utilized, alongside with other trusted sources of information particularly in the blockchain domain.

1.4 Structure of the research

The rest of the thesis is structured as follows. Chapter 2 presents the literature review of this study. Subchapters 2.1-2.4 review previous literature on blockchain technology, starting from the general definition and technical principles of blockchain, continuing to distinguish between public and permissioned blockchains, and finally reviewing smart contracts. In subchapters 2.5-2.7, ERP systems are reviewed, first by reviewing their role in enterprises, followed by different ERP system configurations, and finally reviewing the challenges of current ERP systems. In the subsequent subchapter 2.8 the use of blockchain technology with ERP systems is reviewed in different ERP processes that have been found to have potential with blockchain. Subsection 2.9 presents the most common challenges relating to the blockchain implementation in ERP context. Chapter 3 discusses the main findings and concludes this literature review.

2 Literature review

2.1 What is blockchain?

In essence, blockchain is a decentralized database on a network of computers called nodes, where every node has a copy of the database (Dai & Vasarhelyi, 2017). More specifically, blockchain is "a decentralized and distributed technology that allows for immutable and irreversible information and near-real-time transactions, which are shared amongst public or private participating parties" (Haddara et al., 2021, p. 563). Blockchain is part of distributed ledger technologies (DLT) having its data managed in a decentralized peer-to-peer way (Berdik et al., 2021) without depending on a centralized coordinator or intermediary (Rajasekaran et al., 2022; Rauchs et al., 2018). In DLTs, the participants of the system reach an agreement over the state of the shared database with the help of consensus mechanisms (Rauchs et al., 2018). A consensus mechanism is essentially an agreement over the rule based on which the network participants can propose new data to be added in the distributed ledger (Nguyen & Kim, 2018). Moreover, the data of the distributed ledger is replicated across the participants of the network and made tamper-resistant with the help of cryptographic hashing (Dinh et al., 2018; Rauchs et al., 2018).

What differentiates blockchain technology from the generic definition on DLTs is its ability to maintain data integrity and normal operation under an arbitrary environment where potentially malicious or untrusted network actors are trying to disrupt or take advantage of the system (Dinh et al., 2018; Rauchs et al., 2018). Blockchains use public key cryptography and cryptographic hashing to validate transactions and to make them tamper resistant, leading the system to be resistant to attacks (Aslam et al., 2021). As new block is being added to the end of the chain, its content such as new transactions in the form of Merkle tree root, timestamp, and the hash of the previous block, are included in the block (Rajasekaran et al., 2022). Because the blocks are hashed based on their contents and with the hash of the previous block, even a tiny modification somewhere in a historic block data causes all the following blocks to have different hash representations (Dinh et al., 2018). This way the validators of the network can easily spot an altered version of the blockchain and ignore it in the consensus process.

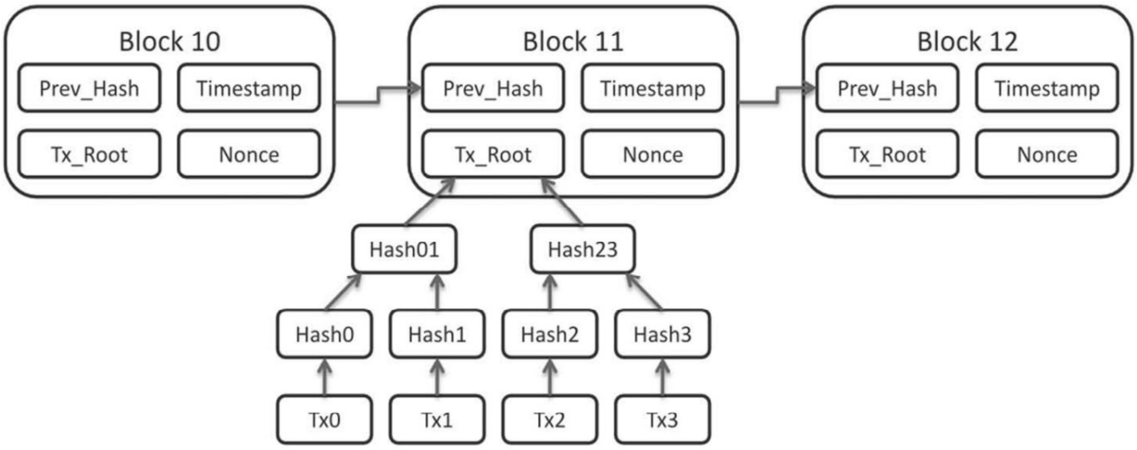

Figure 1. Blockchain design (Nguyen & Kim, 2018)

Blockchain is an append-only database, which means it does not have many operations common to relational databases, such as functions for updating and deleting data (Dai & Vasarhelyi, 2017). Moreover, in contrast to a centralized database management system present in traditional database models (Katuu, 2020), blockchain has a decentralized structure in which the nodes are responsible for its management (Dinh et al., 2018). Decentralization of blockchains results from the consensus processes, due to which no single entity can take control of the network (Dai & Vasarhelyi, 2017).

The key principle behind blockchain consensus is that the state of the network is in accordance with the opinion of most nodes validating it, and that the nodes are incentivized to act honestly for the best interest of the collective network (Nakamoto, 2008). Consensus algorithms range from computationally heavy proof-of-work algorithms to efficient communicational voting-based algorithms (Nguyen & Kim, 2018). Which method is suitable, often depends on the use case of the network and whether the network is permissionless or permissioned (Dinh et al., 2018).

2.2 Public blockchains

In public blockchains, which are also called permissionless, transactions are available to the public and anyone can join to validate the network by running a node and participating in the consensus process (Dinh et al., 2018; Fallucchi et al., 2021; Nguyen & Kim, 2018). Bitcoin and Ethereum are good examples of public blockchains: they are the highest valued blockchains based on their native cryptocurrencies (Coinmarketcap, 2023), besides Bitcoin being the first cryptocurrency and Ethereum the first one to implement next-generation smart contracts (Dinh et al., 2018; Buterin, 2014). What particularly separates public blockchains from permissioned blockchains is their public transaction data, and consensus algorithms designed for public environments.

The Bitcoin network is used for sending BTC, a native cryptocurrency of the network, between addresses. More precisely, transactions are state changes in the Bitcoin distributed ledger suggested by the end-users, validated and executed by the network nodes based on the consensus mechanism (Dinh et al., 2018). In this case, a proof-of-work -consensus mechanism is used. This requires a special node, called miner, to run SHA-256 hashing algorithm on different inputs for so long until it finds a certain input, called nonce, which yields a required output (Nakamoto, 2008). It is only after that, when a validator can propose a new block to the network to be inspected and validated by other nodes, and to be added to the chain. After a successful block is produced and added to the chain, the miner receives compensation in return (Dinh et al., 2018). Because the probability of the miner finding the correct answer to the computational problem is in line with the computing power it uses for the mining, it becomes impossible for a single entity controlling less than half of the combined computing power to take over the control of the network (Nakamoto, 2008).

Ethereum has demonstrated the usefulness of programmable blockchain by being the second largest cryptocurrency by market cap after Bitcoin (Coinmarketcap, 2023). It is the most famous and used blockchain for smart contract development allowing users to create, publish, and execute them on the platform (Fallucchi et al., 2021). Ethereum smart contracts can include arbitrary code and logic (Dinh et al., 2018). The ETH-cryptocurrency is the native asset used to pay for the transaction fees on the network (Buterin, 2014). Until the fall of the year 2022, Ethereum used proof-of-work consensus, before transitioning to proof-of-stake consensus model (ethereum.org, 2023). In the proof-of-stake consensus, nodes must allocate a certain amount of collateral (stake) to be locked on the network, which incentivizes them to validate the network according to the rules or otherwise the stake will be slashed (Lal & You, 2023). The block producer can then be selected based on the amount staked on the network (Nguyen & Kim, 2018). With the help of the new consensus mechanism, Ethereum electricity usage reduced by 99.95% (ethereum.org, 2023) which demonstrates the energy intensity of proof-of-work algorithms.

Besides proof-of-work and proof-of-stake, there are other consensus algorithms such as proof-of-elapsed time and proof-of-space (Nguyen & Kim, 2018). For example, blockchain proposed by Aslam et al. (2021) for an ERP system used proof-of-elapsed since it allows for better throughput and lower costs. However, it is suitable mostly for private permissioned blockchains according to authors.

2.3 Permissioned blockchains

With permissioned blockchains the participants are selected by a central party, restricting the validation of transactions only to relevant parties (Dai & Vasarhelyi, 2017). The terms permissioned blockchain and private blockchain were often used vaguely in the reviewed literature, but some articles considered the term private blockchain to only correspond to an internal tool of an enterprise while a blockchain consortium would also have external parties onboard (Haddara et al., 2021; Nguyen & Kim, 2018). However, both blockchains are permissioned, in contrast to public blockchains. Based on this comparison, Haddara et al. (2021) argued blockchain consortiums to be a potential way to optimize certain functions where collaboration with external parties takes place, since blockchain transparency and the trust it creates were considered the main beneficial characteristics of the technology. In contrast, private blockchain was seen unnecessary since there should already exist trust within a single enterprise (Haddara et al., 2021).

Besides letting only selected participants access the information and join to validate the network, permissioned blockchains are faster, more efficient, and more scalable than public blockchains (Dai & Vasarhelyi, 2017; Dinh et al., 2018). This is largely due to their consensus mechanisms being simpler, often being based on mutual voting (Nguyen & Kim, 2018). For example, Hyperledger, which is one of the most popular permissioned blockchains, uses consensus protocol in which the transactions are committed to the distributed ledger when two thirds of the nodes agree on them. (Aslam et al., 2021). More straightforward consensus algorithms can be used thanks to the limited number of network participants in permissioned systems (Dai & Vasarhelyi, 2017).

Fallucchi et al. (2021) wrote that companies willing to create permissioned blockchains, could use Ethereum in “consortium” mode, where a pre-established group of organizations could manage the blockchain nodes. It was not stated how this could be done but since public blockchains such as Ethereum are open source (Coinmarketcap, 2023), meaning anyone can inspect and copy the source code, it can be used to create a new modified version of the system.

In the business environment, public blockchains have turned out to be unsuitable due to their lack of data confidentiality and inefficiencies (Haddara et al., 2021), and their non-deterministic nature (Dinh et al., 2018). Particularly, proof-of-work consensus model used by many public blockchains has been causing scalability issues and led to high costs which have not been acceptable with large-scale enterprise systems (Aslam et al., 2021). Besides, although blockchain is designed to work on adversarial environments, public blockchains have been viewed risky due to the lack of trust in the network actors (Haddara et al., 2021). Permissioned blockchains, instead, are seen more suitable in business context (Aslam et al., 2021; Haddara et al., 2021). It has also been argued that for an enterprise to get its stakeholders to join the network, permissioned blockchain would be required due to forementioned reasons (Haddara et al., 2021).

2.4 Smart contracts

Smart contracts are automated transaction logic recorded in blockchain, which is set to be automatically triggered based on conditions defined in the contract (Dinh et al., 2018; Fallucchi et al., 2021). What is special with smart contracts in contrast to classic system automation is that being in blockchain environment they get executed without intermediaries (Fallucchi et al., 2021). Dinh et al. (2018) brought up how smart contracts are present in each blockchain as built-in features determining the blockchain's basic transaction logic. However, smart contracts are particularly useful when implemented with additional logic based on use cases that can be arbitrary, and as the complexity and automation increase, they can pose great potential in the enterprise domain (Dai & Vasarhelyi, 2017). Besides with public blockchains such as Ethereum, smart contracts are adopted particularly with permissioned blockchains when it comes to the enterprise adoption (Dinh et al., 2018).

Falluchi et al. (2021) illustrated how smart contracts can be saved into blockchain. The system presented is used by the Ethereum blockchain but is also applicable to other platforms. Here, the role of the file storage system IPFS is to store all the data required for the smart contract, while only the hash of the data returned by the IPFS is saved in the blockchain. This is a key insight, since blockchains have often been considered to lack the ability to handle large amount of data (Dinh et al., 2018). In same way as with ensuring the data integrity with the blockchain transaction history, the hashing function here guarantees the inalterability of the data saved. Whenever the smart contract is used, its data can be accessed via the hash saved in the blockchain. Depending on whether the blockchain is either public or private, this information is accessible to the public or only to authorized users, respectively.

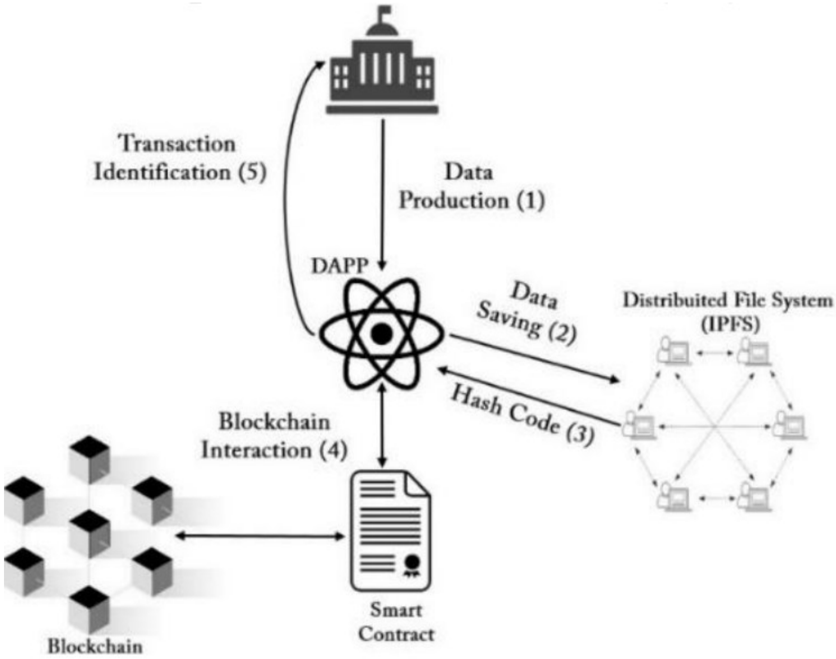

Figure 2. Ethereum smart contract infrastructure (Fallucchi et al., 2021). The decentralized application (DAPP) is used to communicate with the end user.

2.5 Objectives and advantages of ERP systems

Enterprise Resource Planning systems (ERPs) are considered to form the center point of enterprise processes, consolidating information and enterprise functions into a single platform for enterprise-wide use (Aslam et al., 2021; Haddara et al., 2021). Like many other information systems in the business context, their role is to control business workflows, data storage, and data retrieval, while at the same time providing access control mechanisms to restrict unauthorized access (Berdik et al., 2021). ERPs help to connect different business functions and departments such as manufacturing, accounting, finance, sales, supply chain management (SCM), inventory control, human resources management (HRM), and customer relationship management (CRM) (Haddara et al., 2021; Moalagh

& Ghadi, 2022). Moreover, ERP systems help to standardize and automate business processes (Kitsantas, 2022), leading to benefits such as efficiency, elimination of manual labor, accurate reports, and better forecasting and decision making based on consistent data (Mundra & Prakash, 2022). ERP systems have also developed a lot during the last few decades, as they have transitioned from only tracking internal processes and their data, to more holistic systems that help enterprises to reach their goals and value propositions (Moalagh & Ghadi, 2022).

The modern enterprise environment is increasingly competitive and complex, thus proper management of operational processes is more crucial than ever to be cost effective and maintain the desired service levels. ERPs have been viewed as significant enablers of operational functions and processes as they control the flow of information, materials, and funds between the enterprise and its multiple ecosystem partners such as suppliers, retailers, customers, and other stakeholders (Su & Yang, 2010). Moreover, ERP systems play a central role in the web services offered for customers, since in many cases websites use data from the ERPs, for example relating to inventory levels and orders (Aslam et al., 2021).

2.6 Different ERP system configurations

Although ERP system design can vary as much as there are different use cases among enterprises, they have common components. An ERP system is typically a software platform based on single relational database (Katuu, 2020, Azzi et al., 2019). Like other relational databases, they usually are supported by relational database management systems (RDBMS), which help to process transactions automatically while at the same time providing timely and accurate data to support analysis and management decisions (Dai & Vasarhelyi, 2017). Figure 1 presents the usual ERP system design: different business operations and user interfaces have been integrated with one relational database management system.

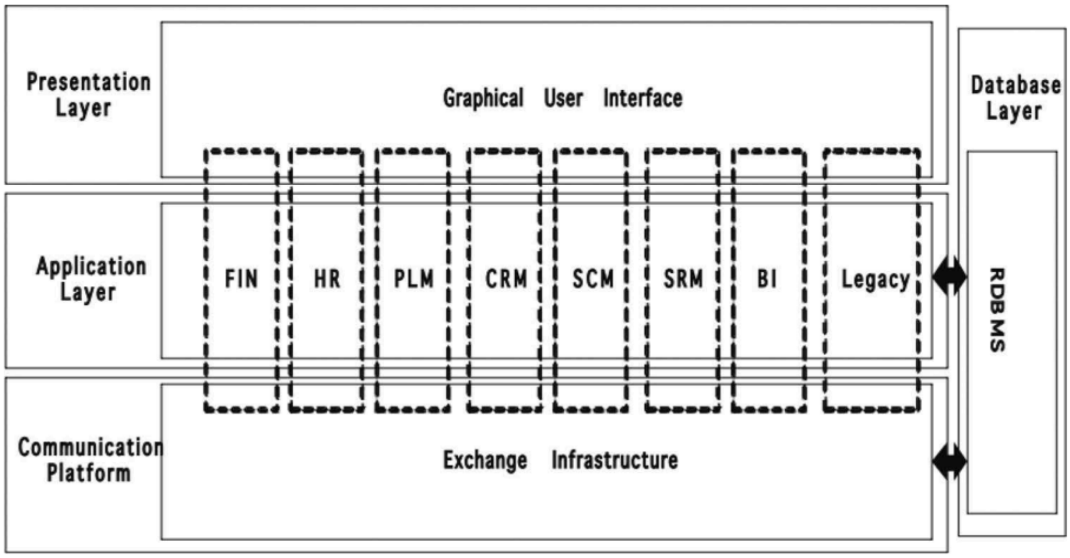

Figure 3. ERP system architecture (Katuu, 2020).

Some of the well-known advantages of relational databases are their ability to store large amounts of data divided in relations, often referred to as tables, in a durable and fault-proof way while at the same time allowing multiple users to access and update the information (Ullman et al., 2007). Furthermore, recovery features with the help of logging and fast execution times of queries are factors that have contributed to the popularity of relational databases (Berdik et al., 2021).

Some of the most popular database management systems are MySQL, Microsoft Access, and PostgreSQL (Berdik et al., 2021). The most important properties of RDBMSs are the safe conservation of data, and the queries and update possibilities based on the relations in the data (Berdik et al., 2021). RDBMSs utilize high-level query languages such as SQL, which still remains a mainstream development language due to its strong theoretical foundation for defining, manipulating, and querying data (Cook, 2018).

To prevent fraud and unauthorized access to data, companies utilize access control mechanisms for both application and database levels in database systems. Access control mechanisms, like Mandatory Access Control, Discretionary Access Control, or Role-Based Access Control model can be integrated in the database system, which can be an efficient way to provide security to the system (Aslam et al., 2021). Besides, monitoring user insertions, modifications, and deletions can be conducted (Aslam et al., 2021).

2.6.1 On-premise ERP

In the case of on-premise ERP systems, the company using the system is responsible for setting up the necessary infrastructure. The system is also managed by the enterprise, either internally or by outsourcing (Kinnunen, 2022). Traditional on-premise ERP implementations are still popular among large companies, since they are suitable for complex and tailored requirements and have low latency (Kinnunen, 2022). Particularly with large manufacturing companies, thorough customization needed for processes is possible to implement with on-premise systems, in contrast to cloud-based systems (Gartner, 2023).

Furthermore, some enterprises think that it is safer to keep all the ERP data at local servers (Gartner, 2023) since in cloud-based ERPs the service provider is solely responsible of the data security (Kinnunen, 2022). Data security can become a relevant issue particularly in public cloud infrastructure, where users share the same cloud resources (Kinnunen, 2022). Moreover, regulations about data sovereignty and provenance can limit possibilities to use certain cloud-based configurations (Gartner, 2023). Behavioral factors also play a significant role in the ERP system selection, as some enterprises may choose to continue the use of their on-premise system due to established habits and satisfaction with the current way of working (Chang et al., 2019).

2.6.2 Cloud-based ERP

A lot of recent research related to ERPs has been conducted about cloud technologies. In cloud-based ERPs, software for the ERP processes is hosted online and maintained by a third-party service provider (Alsharari et al., 2020). The usual service types of cloud-ERP are divided into three categories: Software as a Service (SaaS), Platform as a Service (PaaS), and Infrastructure as a Service (IaaS) (Duan, 2023). In the SaaS-model, customer can buy ERP software packages according to the needs and the service provider takes care of maintaining the software (Bhadra et al., 2019). With the two other options, the cloud service provider runs the infrastructure such as servers, storage, and networking components. In the PaaS-model further platform infrastructure like operating system is also provided (Bhadra et al., 2019).

The development of cloud technologies has led to new service models which take advantage of dynamic resource sharing among the clients and allow for on-demand based pricing (Sandholm &

Lee, 2014). In the modern business landscape where companies aim to grow fast and have many critical business functions online, the cloud-based ERP configuration has grown in popularity (Alsharari et al., 2020; Duan, 2023). Because of the flexible pricing model as well as the fast implementation time, many small to medium sized enterprises have found the configuration suitable (Kinnunen, 2022; Sandholm & Lee, 2014). For new users, it makes it possible to quickly implement a system, since they can just purchase necessary infrastructure or prepackaged software from the service provider. Besides, the subscription-based model can be more suitable since it allocates the costs such as licenses and infrastructure to the customer over a longer period of time. Furthermore, using services from a specialized cloud provider, allows companies to benefit from economies of scale (Kinnunen, 2022).

2.7 Challenges with current ERP systems

There are certain disadvantages and risks common to all ERP systems presented in this chapter. What is common in the systems is their centralized elements that can form a single point of failure, which can lead to vulnerabilities caused either by internal or external actors (Aslam et al., 2021). A single point of failure was also mentioned by Dai & Vasarhelyi (2017), who argued that it could increase the risk of the management tampering with the ERP system. Although in ERP systems different access rights are utilized for different levels of the organization to prevent misdemeanor, such things have still happened as centralized systems do not guarantee tamper-proofness. Besides, the administration procedures of current ERP systems can easily become difficult to manage and costly as organizations grow due to the excess work, surveillance, and inefficiencies they create (Moalagh & Ghadi, 2022).

Factors corresponding to a “single point of failure” could be also technical. For example, a server outage could put a whole ERP system at risk if the system and its data rely on one central platform. Potential data integrity issues pose a major threat to current systems as well, and they can occur if there is no proper system to evaluate erroneous modifications in the database. The modifications can be caused not only by human errors or malicious intent, but also by causes like compromised hardware and cyber-attacks. (Moalagh & Ghadi, 2022)

Berdik et al. (2021) noted how the performance of relational database systems, particularly those that operate under a single database -model, can slow down when the amount of data grows over time. The resulting latency can be caused either from the data retrieval from the data storage or by the filtering of results within the RDBMS. On the other hand, the authors mentioned how an ERP design based on multiple databases can solve latency issues but can lead to inconsistencies between databases.

It was also argued that ERP systems lack connectivity between enterprises and their stakeholders due to having limited communication capabilities (Banerjee, 2018). In supply chain management, this has been argued to cause latency issues in addition to causing lack of trust between entities (Banerjee, 2018). Interoperability challenges with external information systems were also brought up. According to Berdik et al., (2021), there are a wide variety of different systems that implement differing standards for interaction in the healthcare industry. Lack of transparency was also discussed in the reviewed literature. This has been found to cause issues in accounting, where one problem is the possibility of data tampering which has led to many scandals in the past (Moalagh & Ghadi, 2022).

Although ERP systems have been argued to offer solutions to problems presented above, for example by enabling information sharing between an enterprise and its stakeholders (Moalagh & Ghadi, 2022) and by offering access control techniques (Aslam et al., 2021), they have not been efficient enough to overcome these problems. Aslam et al. (2021) thus argument that the problem is in the technology that allows for tampering in certain vulnerable ERP functions, besides not securing transparency as a default characteristic.

2.8 Blockchain use with ERP systems

The concept underpinning this segment of the literature review is to identify ERP functions and processes where blockchain technology has been discovered useful. We now have a satisfactory understanding of both blockchain technology and ERP systems. Moving forward, we will explore the potential advantages of integrating blockchain with specific ERP functions, as identified in the relevant literature.

The emergence of technologies facilitating the integration of blockchain technology with legacy systems has opened up new opportunities. These opportunities enable ERPs to harness blockchain's advantages, including data integrity, immutability, and streamlined transactions. In ERP system domain, blockchain has potential particularly in functions where need to build trust towards external actors exists (Haddara et al., 2021; Moalagh & Ghadi, 2022). This might be why a lot of research has been conducted on supply chains and accounting processes. They both are famous for their complicated and work-intensive nature since much effort goes into clarifications, due diligence, and reporting. Blockchain with the help of its characteristics such as immutability and transparency, has been seen as a potential tool to streamline such functions (Dai & Vasarhelyi, 2017). Furthermore, in ERP functions where the most significance lies in maintaining data integrity and immutability, potential blockchain use cases have been found. These include processes like transactions and asset management.

2.8.1 Connecting blockchain and ERP system

A system design proposed by Aslam et al. (2021) consisted of a blockchain platform which runs in synchronization with a conventional ERP database model. The blockchain's key function was to validate and record every transaction prior to their entry into the ERP database. Access controls which were mentioned by authors as “single point of failure” in the conventional ERP model, were in this case recorded as smart contracts in the blockchain. To respond to the high transaction throughput requirements of ERP systems, only selective data would be recorded in the blockchain (Aslam et al., 2021). This was also mentioned by Dai & Vasarhelyi (2021) who stated that only necessary information should be put into blockchain to keep the system maintainable. Besides, buffers would be used in blockchain nodes to smooth the transaction flow from the end users into the system. Finally, the client application would take care of the flawless end-user experience (Aslam et al., 2021).

This concept mirrored the approach presented by Berdik et al. (2021), where a synchronization between the blockchain and conventional ERP database was established. Furthermore, the authors mentioned how smart contracts would be used to enforce business rules of the ERP system into the blockchain. In addition, smart contracts would take care of the access control mechanisms, ensuring the safety of confidential ERP information.

Kitsantas (2022) focused on a blockchain configuration where blockchain would operate as a middle layer between different companies, forming a blockchain consortium. Blockchain would connect their legacy ERP systems and would act as a trusted platform for common data sharing. Furthermore, companies could migrate existing data from their current ERP systems into blockchain platform, and it could help to automate processes with its smart contract functionalities. Similarly, Banerjee (2018) suggests a private permissioned blockchain which could be product, industry, or business specific.

Forming a central backbone and a source of standardized information among the participants, the blockchain platform would offer several advantages such as operations efficiency, planning capabilities, and data consistency between the participants of the consortium (Banerjee, 2018).

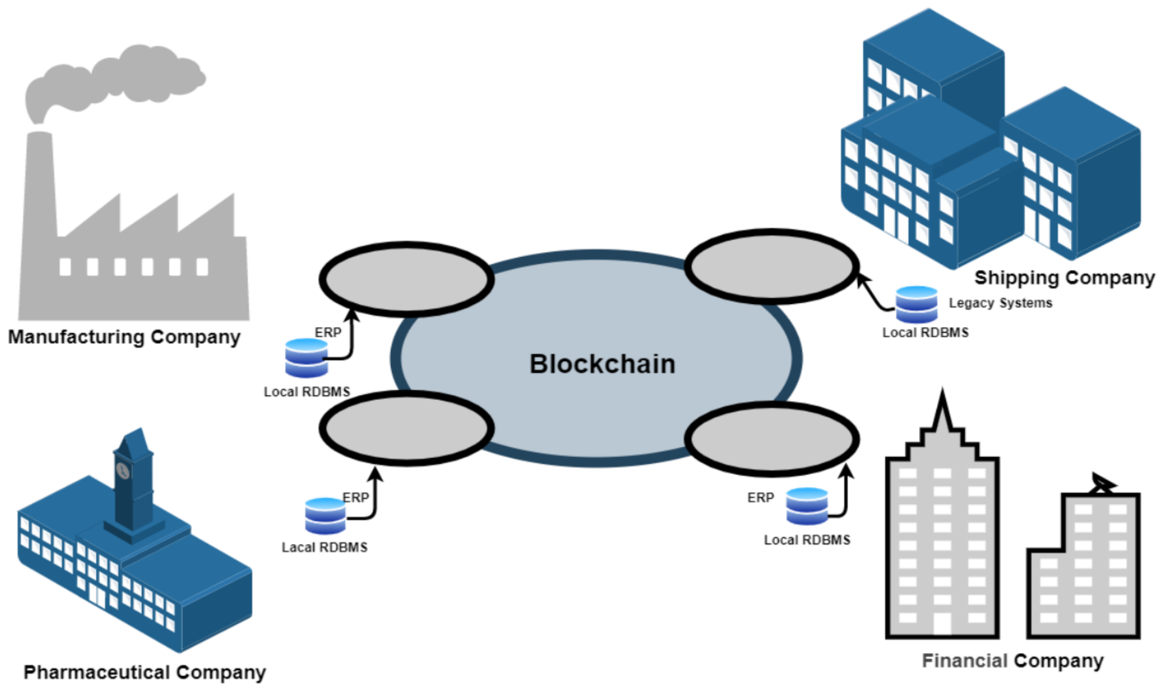

Figure 4. Blockchain as a middle layer between ERP systems (Kitsantas, 2022)

Enterprises do not have to pay too much attention to the technical details if they decide to adopt blockchain as a service -model. According to Kitsantas (2022, p.12), blockchain as a service (BaaS) "is a combination of cloud-based hosting services that allow businesses to develop, host, and manage their own applications, nodes, smart contracts, and distributed ledgers in a cloud ecosystem, which is managed and administered by cloud-based providers". The most popular providers include IBM, Oracle, and SAP, and besides offering modules, layers, and interfaces for their blockchain solutions, they offer integration services making the process simple for enterprises (Kitsantas, 2022).

2.8.2 Supply chain management

Supply chains have become more complex, but current ERP systems have not been able to adopt new requirements of transparency, flexibility, and data accessibility (Azzi et al., 2019). Because of the new requirements, the area has been viewed as having the most potential to benefit from blockchain technology (Belhi et al., 2021). A common problem that enterprises face in supply chain functions is the lack of visibility among partners, orders, and in product provenance (Banerjee, 2018). Furthermore, traceability and data management have remained as further challenges in supply chain functions (Azzi et al., 2019). Haddara et al. (2021) mentioned that the inadequate external communication abilities in supply chain functions with today's ERPs is problematic. Transparency of blockchain, enabling "a single source of truth" and a common source for shared information among supply chain participants, was considered a solution. Finally, standardization of data is another factor further streamlining communication. Banerjee (2018) argues the idea of common decentralized environment among a consortium of enterprises by stating that unlike with traditional consortiums of data sharing, a blockchain-based consortium would enable standardization of data, leading to effective interaction and trust between enterprises that have integrated their ERP systems into the network.

All key properties of blockchain; traceability, decentralization, and immutability (Haddara et al., 2021), can enhance supply chains functions of ERPs and offer solutions to the abovementioned problems. Perhaps blockchain's most important value proposition in the supply chain context is visibility enabled by the transparency component of blockchain. Haddara et al. (2021) stated that the ability to track various actors and the flow of physical goods are seen as the most demanded features of blockchain in the supply chain domain. The authors state that blockchain integration would lead to benefits such as efficient communication, reduced waste, and detection of fraud since the participants of the supply chain can trace the products and their history logged in the blockchain used by the collaborating entities. Azzi et al. (2021) also brought up the increased traceability. Tracking systems with the help of sensors, tags, and a blockchain data storage layer, were considered potential ways to increase supply chain transparency, although it was mentioned how they require additional processes to prevent fraud with the tagging processes.

A better view of the flow of goods in the supply chain can be useful when companies need to be aware of the provenance of products. This can be crucial for example due to local laws and tax incentives, which further emphasize the need for better visibility in supply chains (Berdik et al., 2021; Dai & Vasarhelyi, 2017). Besides, compliance with international standards can be achieved with the help of the blockchain traceability (Azzi et al., 2019).

Immutability of blockchain can further streamline and clarify communication, reduce waste, and detect fraud among supply chain participants since the information about the products and their history cannot be tampered with. Moreover, it could lead to better decisions based on higher-quality data. (Haddara et al., 2021)

Finally, the usefulness of smart contracts in the supply chain realm was noticed in the reviewed literature. They were seen as a more reliable way to conduct transactions and their logic could be based on the traceable provenance of goods, enabling quicker issue tracing (Berdik et al., 2021). However, Berdik et al. (2021) did not seem to focus on the automated processes enabled by smart contracts, but instead viewed smart contracts as conventional contractual methods. As we have found in this thesis, smart contracts have further potential than only operating as legal instruments, thus the review should have been more thorough.

2.8.3 Accounting processes

In the accounting functions of ERP systems, transparency and immutability of blockchain have been considered important value propositions, alongside with improved efficiency of operations such as auditing, taxation, and reporting (Dai & Vasarhelyi, 2017; Dulani Jayasuriya & Sims, 2023). Furthermore, smart contracts play an important role when adding functionality to accounting processes. Permissioned blockchain was considered a suitable option since the validation of accounting transactions should be conducted only by relevant parties (Dai & Vasarhelyi, 2017).

To increase transparency between an enterprise and its stakeholders such as auditors, creditors, and tax officials, Dai & Vasarhelyi (2017) propose an accounting system in which blockchain would operate in synchronization with the existing ERP system. The stakeholders would have access and would participate in the validation of the blockchain network, where the functions of automatic information verification, processing, storing, and reporting take place. These functions would operate in real-time and could enable streamlined information sharing between an enterprise and its stakeholders, reducing the need for manual information gathering and sharing. Inter-organizational data management between an enterprise and its stakeholders was brought up by Dulani Jayasuriya & Sims (2023) as well, being argued to allow streamlined and real-time co-operation between the parties. Efficiencies regarding taxation were brought up as one major benefit resulting from real-time information sharing from blockchain-based accounting information system.

Besides external reporting, blockchain utilization in accounting systems could significantly reduce the need for manual monitoring of business processes in internal audit, according to Moalagh & Ghadi (2022). Furthermore, real-time auditing enabled by blockchain could significantly decrease data manipulation and other fraudulent methods potentially conducted by managers (Dulani Jayasuriya & Sims, 2023). Finally, access controls employed in the blockchain could be used to manage access for the information for different parties (Dai & Vasarhelyi, 2017).

To automate these processes, smart contracts could be utilized. Smart contracts could also be used to monitor processes and trigger warnings and possibly automatically make corrections, for example in a situation when a manual entry causes a violation of an accounting principle. Moreover, smart contracts could be utilized with Internet of Things (IOT) -technologies, monitoring the physical flow of goods. The monitoring could be streamlined and recorded in blockchain, to allow for better accounting compliance for example when location information of goods is needed for accounting purposes. The smart contracts used in accounting should be validated by relevant professionals, such as auditors, lawyers, and regulators. (Dai & Vasarhelyi, 2017)

Immutability and traceability offered by blockchain could make the accounting information more reliable leading to more efficient audit processes (Dai & Vasarhelyi, 2017). Data management with the help of immutable and verifiable records were also mentioned by Dulani Jayasuriya & Sims (2023). In addition, traceable and immutable information of transactions, such as invoices and payments, could prevent disputes (Moalagh & Ghadi, 2022).

Finally, tokenization of accounting entries was also brought up by Dai & Vasarhelyi (2017). Tokens could represent anything, such as obligations or just transfers between accounts. The key value proposition here is the programmability enabled by tokenization. Thus, arbitrary logic could be implemented to follow specific accounting and ERP system rules.

2.8.4 Decentralized access controls

Berdik et al. (2021) argued how blockchain enabled decentralized access controls is one of the most practical use cases of the technology presented in the literature related to blockchain and business information systems. This was seen relevant with cloud-based systems, and the decentralized aspect of the access control system would make the system itself and the processes that are being protected safer, by reducing the trusted third party from the process. Although the study did not focus particularly on ERPs, it is relevant to the subject since many ERPs operate on cloud-based environment (Kinnunen, 2022) and they share similar problems (Aslam et al., 2021; Moalagh & Ghadi, 2022).

2.8.5 Assets

Immutable records and near real-time transactions enabled by blockchain were considered to be beneficial characteristics in asset management within enterprise systems (Haddara et al., 2021). They were seen suitable for managing physical flow of goods in inventories and along the supply chain functions leading to better quality and consistent data (Banerjee, 2018). Moreover, arbitrary information can be saved and transacted with blockchain, including large files of information. As mentioned in part 2.4, this can be done with the help of an external storage solution like IPFS, in which case only the IPFS hash of the content is saved in the blockchain.

Tokenization of assets has potential to reform how enterprises manage their resources since tokens can be programmed to represent and conduct various things (Haddara et al., 2021). Domains of tokenization, such as customer relationship management, inventory items, and accounting documents, were mentioned by Dai & Vasarhelyi (2017) and Haddara et al. (2021). The tokenization of assets could add programmability on top of the current practices, creating new and innovative ways for enterprises to have control over their assets. Fallucchi et al. (2021) also brought up tokenization of assets, stating that intangible assets like patents and licenses, could be made programmable once registered in blockchain.

2.8.6 Transactions

Blockchain technology in the payment functions of ERPs is considered to enable faster and cheaper transactions, due to the elimination of middlemen (Haddara et al., 2021). Besides the benefits of decentralization, programmability offered by smart contracts could streamline and automate transactions enabling instant payments based on the ERP data integrated on the blockchain. In addition, immutability and traceability can help to achieve trust in transactions with external parties and enable immutable audit trails in the accounting functions (Moalagh & Ghadi, 2022).

Instead of the document- and report-based practices that are used today by enterprises to express their financial situation, integrating ERP data into a blockchain consortium involving collaborating enterprises could provide these enterprises with insights into each other's payment capabilities (Haddara et al., 2021). This is considered to pose great potential since enterprises would not have to rely on historical information used by current reporting conventions. Aslam et al. (2021) further argues that transparency allowed by such systems could lower the cost of tracking and reporting.

2.9 Challenges with blockchain solutions

Although this study focused on advantages of the presented technologies, it could be appropriate to mention some of the drawbacks as well. The literature reviewed during this thesis identified similar challenges, many of them concerning data privacy and costs. Technical obstacles were also significant, but they largely depended on the blockchain configuration and the industry domain.

The challenge of reduced transaction privacy was mentioned by Haddara et al., (2021). This issue was not limited to public blockchains, where transactions are public information, but the problem is also present with blockchain consortiums as enterprises want to restrict the amount of data they share to their partners.

Implementing blockchain technology can be costly, and its adoption may require letting go of some existing work practices. Thus, investments in the technology can be difficult to justify unless the benefits are clear (Haddara et al., 2021). Furthermore, the absence of blockchain standards could lead to labor-intensive and expensive implementation processes across various functions of ERP systems (Belhi et al., 2021).

Technical immaturity of blockchain protocols was brought up by Dinh et al. (2018). He stated that Ethereum is one of the few protocols that have mature codebase, userbase, and developer community. He also stated that the lack of interoperability between blockchain protocols causes difficulties, due to their different programming models.

The low data processing performance of blockchains compared to current database systems was also argued (Dinh et al., 2018). The authors acknowledged that although incumbent database systems are not built to be fault tolerant in the same way as blockchains, the performance difference is too high in order for blockchains to become disruptive. Finally, concerns have been raised about the potential difficulties associated with updating blockchain systems, although this was not deemed to be a major barrier to adoption (Haddara et al., 2021).

Lastly, the lack of regulations and regulated standards in blockchain design was considered to be a factor hindering blockchain adoption, introducing risks to blockchain projects (Dai & Vasarhelyi, 2017).

3 Discussion and conclusions

We started this thesis with the intention to find out what advantages could blockchain technology bring to current enterprise resource planning systems. More precisely, we began looking for answers with the help of the three research questions: 1. What is blockchain technology and what are its advantages? 2. What are ERP systems and what are their advantages? 3. What advantages does blockchain technology offer in different ERP functions? We started with a comprehensive review of blockchain technology by discussing its main principles, technological features, and key characteristics. We found out that the technological building blocks of blockchain, such as cryptographic hashing and consensus algorithms, allow us to establish an immutable and traceable network where the integrity of the data is secured without the need of a third party. In addition, we pointed out that blockchain differentiates itself from other distributed ledger technologies with its ability to operate in adverse environments, eliminating the need of trust to other network participants.

We then went on to distinguish public blockchains from permissioned blockchains. We noted how the inefficient consensus mechanisms as well as the lack of data security and trust in public blockchain networks have made them unpractical for enterprise use. In contrast, permissioned blockchains and particularly permissioned blockchain consortiums, were seen suitable in business context since they have solved out the problems stated with public blockchains. We also found out that smart contracts were an important part of blockchain technology. They have extended the utility of blockchain beyond simple transactions to enable the execution of arbitrary code according to predetermined logic, and they have posed great potential to the enterprise domain creating opportunities of automation.

The second research question focused on ERP systems. We examined the operations performed by ERP systems and assessed the advantages they offer. We described how they form the operational backbone of most modern enterprises, integrating departments, processes, and data into a unified platform, resulting in benefits such as enhanced operational efficiency and consistent data. Additionally, we reviewed how relational databases form a technical backbone of current ERP systems due to their well-known advantages, and distinguished between the two usual types of ERP system configurations: on-premise- and cloud-based-ERP system. Finally, we presented the common challenges in ERP systems. It was found out that tampering of data, interoperability challenges, and technical vulnerabilities pose significant risks to ERP systems. Reason we identified behind the problems was the centralized architecture of ERP systems, forming a single point of failure.

The third and final research question focused the advantages offered by the integration of the reviewed technologies. First, different integration possibilities found in the literature were reviewed. In certain articles, the blockchain was responsible for validating transactions and guaranteeing data integrity in synchronization with the existing ERP software, while in other articles blockchain's ability to connect enterprises as a middle layer between their ERP systems was highlighted.

The most promising application areas in ERPs context according to the reviewed literature were supply chain management and accounting. In supply chain processes, all key blockchain characteristics; traceability, decentralization, and immutability, were considered relevant. Better visibility into the supply chain, streamlined communication with the help of standardized data, and immutable records, would together create better collaboration practices for the members of a blockchain consortium. In accounting processes, transparency and immutability of accounting data, and particularly enhanced collaboration possibilities with authorities were seen key advantages, and they would also reduce the reliance on manual auditing processes. Again, permissioned blockchain was proposed as a network which would include the enterprise and its relevant stakeholders. Decentralized access controls enabling better security practices, immutable and real-time asset tracking, asset programmability enabled by tokenization, and streamlined transactions were further application areas of blockchain technology within ERP functions. Finally, it is noteworthy that smart contracts were recognized as a way to replace manual processes and further enhance efficiency in all the blockchain application areas.

3.2 Implications to practice

Based on the findings of this literature review, permissioned blockchains, particularly blockchain consortiums, were found suitable for enterprise use. Therefore, the potential integration of permissioned blockchain into ERP processes should be considered by mangers. Blockchain has potential to streamline processes, particularly in the supply chain management and accounting processes of enterprises. Managers should consider the potential advantages blockchain could bring to their processes and whether the advantages can justify the required investment and replacement of current practices.

3.3 Limitations and suggestions for future research

This thesis focused on technological principles and advantages of blockchain technology and ERP systems, in addition to identifying the most potential application domains of blockchain in the usual ERP processes. We did not focus on the organisational or legal aspects of the technologies, nor did we focus on the potential challenges besides mentioning the most common ones encountered during the writing of this thesis.

More research should be done on the challenges related to blockchain implementation since this study focused exclusively on the potential advantages. In addition, more research could be conducted on recent practical applications of blockchain technology within ERP functions since the literature was scarce in this domain.

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