Examining and Evaluating Potential Blockchain Applications in Manufacturing and R&D

Peter Soldner
Abstract

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Blockchain – the technology behind virtual currencies such as Bitcoin – is being promoted by many as one of the most promising emerging technologies. At its core the blockchain is a distributed, immutable data base, able to pinpoint exactly when and by whom a given transaction has been made. Similar to the internet in its early days, blockchain (often referred to as Distributed Ledger Technology) must be seen as a foundational technology, enabling a great variety of potential applications. The blockchain’s greatest potential lies in its ability to disintermediate and optimize very specific processes, companies should first evaluate exactly where and how they could benefit from it and whether blockchain-based solutions could provide an advantage compared to traditional ones. Some of the blockchain’s key advantages include disintermediation, improved traceability of products, increased transparency of transaction histories, as well as enhanced security of records regarding fraud and unauthorized activities. Within manufacturing industries, some of the most promising applications of the technology lie in the field of supply chain management and logistics, distributed manufacturing (e.g. 3D-printing), as well as the Internet of Things (IoT). R&D departments might be able to use the technology as a way to defend intellectual property, similar to how they could use a notary service. Blockchain enabled 3D-printing might also be of interest in the case of low production volume samples and prototypes.
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<tbody>
<tr>
<td>CARS</td>
<td>Credibility, Accuracy, Reasonableness, Support</td>
</tr>
<tr>
<td>GDP</td>
<td>Gross Domestic Product</td>
</tr>
<tr>
<td>IIot</td>
<td>Industrial Internet of Things</td>
</tr>
<tr>
<td>IoT</td>
<td>Internet of Things</td>
</tr>
<tr>
<td>IT</td>
<td>Information Technology</td>
</tr>
<tr>
<td>MB</td>
<td>Megabyte</td>
</tr>
<tr>
<td>R&amp;D</td>
<td>Research and Development</td>
</tr>
<tr>
<td>SAMPL</td>
<td>Secure Additive Manufacturing Platform</td>
</tr>
<tr>
<td>tps</td>
<td>Transactions per second</td>
</tr>
<tr>
<td>US</td>
<td>United States</td>
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1. Introduction

Blockchain, the technology behind Bitcoin, has been a controversial topic in recent years. Many experts see great potential within various industries, and applications of the technology are not only found in the finance industry. While opinions on the technology often vary, interest has certainly spiked, and given the World Economic Forum's 2015 estimate that 10% of the global gross domestic product (GDP) will be stored on blockchain technology by 2027, it is likely that the technology will affect business processes in one way or another (World Economic Forum, 2015).

1.1 Problem Discussion and Research Objectives

Due to the ongoing public interest, as well as the foundational nature of the technology, many potential use cases for blockchain technologies have been proposed in recent years. While the financial industry already has a selection of functioning blockchain applications, mainly in the form of cryptocurrencies, many of the use cases within other sectors are merely ideas or initial concepts at this point, which makes it difficult to distinguish between fact and hype.

The same is true for blockchain applications within manufacturing industries, an area that is starting to receive more and more attention. Therefore, the purpose of this thesis is to a) identify and describe potential blockchain applications within manufacturing industries on an operational level (Objective 1).

A subject that so far has only received little attention, however, is the blockchain's relevance in regards to product development activities within manufacturing industries. Thus, the second main objective of the thesis is to b) examine how the technology can be used within manufacturing R&D departments (Objective 2).

For both, objective 1 & 2, potential use cases were either found in existing literature or ideated by the author.

Once the study has been able to identify different scenarios in which blockchain technology could be used in a manufacturer’s R&D setting, the main research question of this thesis, as presented below, can be addressed.

"Which potential application of blockchain technology could generate the greatest impact on R&D activities within manufacturing industries, and how likely are established manufacturing companies to adopt the use case?"

1.2 Content

In order to create a better general understanding for the subject, chapters 4, 0 and 6 will provide the reader with necessary background information about blockchain technology, as well as examine the nature of the technology from a theoretical perspective.

Chapter 7 aims to give the reader an idea of how the technology can generally be used by explaining in which environments and under which factors the use of blockchain technology can be beneficial. It also provides various examples of applications across different industries.

The latter half of the thesis shifts the focus towards the manufacturing industry. While chapter 8 describes how the technology can generate value for manufacturing companies (Objective 1), chapter 9 tries to identify potential blockchain applications in Research & Development (Objective 2).
1. Introduction

In order to better understand how the technology could be applied to an R&D setting different industry experts have been interviewed, and both the results as well as an interpretation of these results are presented in an analysis (chapter 10). This chapter also evaluates how the newly gathered results compare with the theoretical background provided in chapter 5 and 6.

At last, a final conclusion is presented in chapter 11, which also contains a personal opinion and recommendations.
2. Background

As indicated in chapter 1.1, the term *blockchain* has been used quite loosely in recent times. Many projects, companies, or research groups are promising blockchain-based products that they claim will solve a variety of problems. Like for most other industries, there have also been many proposals on how blockchain could be used in a manufacturing and R&D setting.

In order to better evaluate their actual potential, the idea was to present industry experts from manufacturing and R&D with potential use-cases, and have those experts evaluate them based on their experience, insight, and knowledge. A partnership with *3DSE Management Consultants GmbH*, a Munich based consultancy with expertise in product development, systems engineering, agile product development and other R&D related topics, would not only allow access to various experts from client-companies, but also a day to day interaction with experienced consultants within the company.
3. Methodology

3.1 Research Philosophy
For the purpose of the study, interpretivism was chosen as the favored research philosophy. As opposed to positivism, which tries to compress insights into universal, law-like generalizations, interpretivism promotes the exploration and interpretation of situational details (Saunders et al., 2009).

3.2 Research Approach
By its nature, deductive reasoning requires a predetermined hypothesis which will then be tested and evaluated throughout the study. Due to the nature of the topic, as well as the research question, a detailed hypothesis would have been difficult formulate. Therefore, a more inductive research approach was chosen. Inductive reasoning requires the researcher to take an active role in the research process, as well as an overall more flexible structure that allows for agility throughout the research project. Such an approach further requires a good understanding about the research context which, considering the novelty and nature of blockchain-technology, would be a large part of the overall project. A solid understanding of the technology was also required as, for research objective 2 in particular, use cases from different industries were transferred into an R&D setting. Having an industry partner would make it possible to set up in-depth, personal interviews with various industry experts (qualitative data). Therefore, another reason for choosing an inductive research approach was that inductive reasoning favors qualitative over quantitative data collection, as well as being less concerned about having to conclude generalizations from the data obtained (Saunders et al., 2009).

3.3 Research Strategy
Since answering the research questions requires a deep understanding of the context in which blockchain-technology will be applied, a case study approach was chosen. As case-studies allow for a variety of different data collection techniques to be used, they can bring flexibility to the research process. Triangulation – validating data by using different data collection techniques within the case study – was achieved by using interviews, as well as a questionnaire at the end of each interview. Since all interview partners come from a different company and have unique backgrounds, the research strategy consists of multiple cases, as each interview could be considered its individual case study (Saunders et al., 2009).

3.4 Theoretical Choices
In order to give the reader a better understanding of how new technologies generally behave in a market, chapter 5 will explain different theoretical concepts. Apart from defining the term innovation, this chapter will also explain the process of how new technologies are adopted over time (technology adoption), as well as how technologies improve over time (technology improvement). Furthermore, different factors that can either prolong or shorten a technologies lifecycle will be described (chapter 5.4). To present the reader with an idea about how new technologies are often perceived by the public, the theory behind the famous Gartner Hype Cycle will be explained (chapter 5.5). In chapter 6 the difference between disruptive- and foundational technologies will be explained, and how this distinction affects the technologies adoption process.
3. Methodology

3.5 Validity
Validity describes the accuracy – the degree to which an answers relates to the question – of a study (Mohajan, 2017). Thus, when interpreting the results of the expert interviews, it is crucial to realize that answers can be subjective. For example, when asking about the business-implications of a given technology use-case, one must keep in mind that the interview partner might unconsciously answer the question with his or her personal background or company-role in mind. The thesis tries to improve validity by conducting a total of seven in-depth interviews, thus decreasing the effect of each interview partner’s personal background on the overall score. However, an even greater sample size would further increase the study’s validity.

3.6 Reliability
Due to the inductive research approach, as well as the technologies high degree of novelty, it must be noted that inter-rater reliability, which essentially describes the consistency of study results when performed by different researchers, is difficult to fully ensure (Mohajan, 2017). Not only would another researcher maybe come up with different use-cases, the way in which a different researcher would explain the use-cases to the interview partners could also have an effect on their respective opinions.

Intra-rater reliability, or the consistency of repeated tests by the same researcher, is more likely to be established since the interview-process, especially when explaining the use-cases, was practiced in advance and followed a consistent structure (Mohajan, 2017).

3.7 Bias
Bias can be described as “any trend or deviation from the truth in data collection, data analysis, interpretation and publication which can cause false conclusions” (Šimundić, 2013, p. 1). Both, interview partners and researchers can be subject to bias. In order to minimize the deviation from the truth it is not only crucial to acknowledge that bias does exist, but also to try identifying its sources and where it might be most prominent.

3.7.1 Bias in data interpretation
When researching a given technology over an extended period of time, researches often develop their own opinions on where and how the technology can be used. While a solid understanding about the technology is crucial for inductive research, researches must ensure to not interpret findings in favor of their already existing beliefs (Šimundić, 2013).

3.7.2 Sample bias
Since it is impossible to interview an entire population (e.g. every person working in R&D), a sample needs to be selected. However, this sample should be selected in a way that best represents the population (Šimundić, 2013). In this case it was a main goal to find interview partners from different industries and with different roles.
3.8 Ethics
Research ethics is trying to answer how a research topic should be formulated, how data should be collected, stored, processed, and analyzed, as well as how findings should be formulated in a moral and responsible manner (Saunders et al., 2009). The Respect Project has brought forward a well-defined code of practice for ethical research consisting of three main principles, each explained in great detail and with various sub-categories. While the first principle describes how scientific standards can be ensured, the second principle explains how compliance with regulations and laws can be ensured. The last principle touches on how to avoid social and personal harm in research (The RESPECT Project, 2004).

3.9 Sources and Data Collection
The information gathered throughout the research project can be categorized in literature sources, oral sources, and primary data.

3.9.1 Literature sources
Due to the inductive research approach, the first main task was to develop a good understanding about blockchain-technology. The most consistently used approach to acquire in-depth knowledge was extensive literature research. Literature came from both, primary- and secondary sources.

Primary literature sources:
Primary literature sources are often described as the first occurrence of a particular piece of information (Saunders et al., 2009). In this case, primary literature mostly came in the form of company white-papers (e.g. white-papers on a particular blockchain-protocol), and other company publications such as website-content, or company reports. Since primary literature sources usually are not subject to review-processes, content needs to be taken skeptical.

Secondary literature sources:
Once a primary literature source has been published it is often categorized as secondary literature (Saunders et al., 2009). Thus, secondary literature often came from sources like published books, scientific-/industry journals, newspapers, magazines, and other digital sources such as websites. This type of literature would account for most of the overall literature analyzed throughout the research project. Due to the general hype surrounding the topic it was important to evaluate the creditability of the various sources. In order to ensure quality of sources the CARS (Credibility, Accuracy, Reasonableness, Support) Checklist for Information Quality as introduced by Harris (2010) was applied. During this phase, literature research was complemented by two informal phone interviews with IT-experts with knowledge in blockchain technology.

3.9.2 Non-written secondary sources:
Apart from primary- and secondary literature sources, information was also gathered from audio- and video material found on the internet. Especially during the early stages of the thesis, where the main focus was on understanding the technology itself, animated YouTube videos and recorded expert interviews were a valuable source of information. It must be noted that information taken from YouTube or similar platforms is not very reliable and should therefore always be confirmed by published literature. However, they were mostly used as a starting point for further literature research, as they often helped clarifying what to search for.
3. Methodology

3.9.3 Primary data collection

During third phase of the thesis, the different concepts of blockchain in R&D, whose basic feasibility has already been proven at this point, were further examined. Information was gathered through seven one-hour interviews with R&D experts from various companies, which were followed by a questionnaire.

Semi-structured interview:
The reason for choosing semi-structured interviews was that by eliminating tight boundaries, a rather open discussion about the applicability, usefulness, and future of the different use-cases would be encouraged. This interview form would also allow to vary the questions themselves, as well as their particular order depending on the participant’s individual background. Furthermore, questions would mostly have an open character (Saunders et al., 2009). As suggested in (Blandford, 2013), interviews were given structure by having the interview separated in different sections, as well as having various key questions already prepared. After a brief personal introduction, interviewees were asked about their already existing knowledge on blockchain technologies. This existing knowledge was then supplemented by additional explanations about the technology. Once a basic understanding was ensured, participants were introduced to the different use-cases. In order to allow for a better conversational flow, the entire interview was audio-recorded and only important written comments were made (Saunders et al., 2009). Permission for audio-recording the interview was obtained by having participants sign a consent form.

Questionnaire:
With the help of a final questionnaire, participants were asked to quantify their beliefs about the potential, likelihood, and implementation time frames of each use-case. While potential and likelihood were to be rated on a scale from 0 to 10, implementation time frames were assessed in years. Given the three presented use-cases and the three dimensions explained above, a total of nine values were needed to complete the questionnaire. After an initial explanation of the process, interaction between participants and the interviewer was kept at a minimum in order to ensure an unbiased response (Saunders et al., 2009).
4. The Underlying Technology

According to a 2016 survey conducted by Deloitte, blockchain technology is becoming a key business focus for US companies in various industries. However, the same survey also found that knowledge about the technology is often rather limited (Schatsky & Piscini, 2016). The following will therefore try to give a basic understanding of Bitcoin’s underlying technology.

4.1 Definition

The term *blockchain* was first introduced in a white paper about the virtual currency bitcoin. The nine-page paper, which describes Bitcoin’s underlying technology, including functions and algorithms, was published in 2008 by the anonymous author(s) behind the pseudonym Satoshi Nakamoto (Nakamoto, 2008). Since then, many experts have brought forward different definitions on what the blockchain really is. The following two have been selected by the author.

Don and Alex Tabscott, authors of *Blockchain Revolution*, defined the blockchain as follows:

> “The blockchain is an incorruptible digital ledger of economic transactions that can be programmed to record not just financial transactions but virtually everything of value.”

(Rabosky, 2016, p. 48)

Jennifer Rideout explained blockchain as

> “a continuously growing list of records or transaction between peers that are linked together sequentially in blocks. Each block in the link (or chain) contains a cryptographic hash for the previous block, a timestamp and transaction data. Blocks include a record of every transaction that occurred on the network during that period, and every transaction is validated to guarantee accuracy.”

(Rideout, 2018, p. 1)

4.2 How Blockchain Technology Works

At its core, blockchain technology uses peer-to-peer networking, cryptography and game theory, all of which have been around for years. Blockchain, however, presents a new concept of combining the three (Figure 1).

![Figure 1. Blockchain's underlying technologies](source: own representation based on Voshmgir, 2016, p. 13)

As the blockchain exists across an entire network of computers, there is no need for centralized servers (Lord, 2016). The blockchain allows for information to be recorded and shared by a community, with all members having a copy of the information and collectively validating new information (Trouton,
The Underlying Technology

Vitale & Killmeyer, 2016). New information is added in the form of blocks, which are chained together using complex computational algorithms. This process is what gives the blockchain its name. Furthermore, each individual computer (called ‘node’) within the network has a complete history of transactions, starting with the very first block (Woodside, Augustine & Giberson, 2017).

In other words, the blockchain is a network of nodes all running the same protocol and holding an identical copy of the ledger of transactions. Through the concept of machine consensus, transactions can be carried out without the help of intermediaries (Voshmgir & Kalinov, 2017).

Figure 2. Basic blockchain structure (source: own representation)

4.2.1 Five basic principles of blockchain

In order to better understand the technology, it can be helpful to explore the blockchain’s most fundamental attributes. Iansity & Lakhani (2017), for example, concluded that blockchain is best described by the following five principles:

1. Distributed database:
   Every node within the blockchain is granted access to the entire database, can see its complete history, and can directly verify its partner’s transaction records without the need of an intermediary. There also is no singly party that has control over the data or the information.

2. Peer-to-peer transmission:
   Communication between peers occurs directly, thereby eliminating the need for a central node to store and forward information.

3. Transparency with ‘pseudonymity’:
   Every user within the blockchain in represented by a 30-plus-character alphanumeric address. Every transaction and its associated value is linked to the user’s address and clearly visible to all other nodes on the blockchain. However, since a user’s alphanumeric address alone does not reveal any personal information by itself, it is up to the users to decide whether to proof their identity to other users or remain anonymous.

4. Irreversibility of records:
   Different computational algorithms (further explained in 4.2.2) ensure that a transaction that has been entered on the blockchain stays there permanent. This is due to the fact that the new transaction is now linked to every other transaction record before.
5. **Computational logic:**
Due to the digital nature of the blockchain and the independence on intermediaries to validate transactions, these very same transactions can be tied to computational logic and essentially be automated and programmed.

![Blockchains architecture](image)

**Figure 3. Client/Server and Peer to Peer networks** (source: own representation based on Phillips, 2014)

### 4.2.2 Blockchain’s architecture explained

The following sub-chapter will try to explain the blockchains basic architecture, its working mechanism, as well as its most fundamental components.

**Blocks:**
As already indicated by the name, a blockchain is made up of a series of blocks, with every block containing a specific set of information. The type and amount of information per block is defined by the blockchain’s individual protocol. On the bitcoin blockchain, for example, blocks contain a set of transactions with a limit of 1 MB. If address A was to send x-amount of bitcoin to address B, this and many other transactions would be stored within a block and subsequently added to the blockchain (Drescher, 2017). Apart from the actual data, each block also contains a timestamp, the previous blocks hash value, as well as its own hash value (explained below).

**Hash values:**
A hash value could essentially be described as the *digital fingerprint* for data. With the help of a hash function, any kind of data (input) can be turned into a unique hash value (output). Hash values are numeric numbers with a fixed length, which does not depend on the size or type of the input-data.

Hash functions are *one-way functions*, meaning that the same input-data will always result in the same hash value, but there is no way of recreating the input-data from the hash value alone. They can further be regarded as collision resistant, since they can be designed in a way that makes it virtually impossible to receive the same hash value as an output, unless the input-data is identical (Drescher, 2017).

**Timestamp:**
As every block, as well as every transaction, contains a timestamp, it allows to effectively identify the exact time and data a given transaction was conducted (Drescher, 2017).
4. The Underlying Technology

Linking blocks:
As the term blockchain suggests, blocks are permanently linked together similar to links in a chain. This is achieved by using the hash value of the previous block as one of the input-data for the hash function of the current block. This means that the hash value of any given block directly depends on the hash value of the previous block.

If we take into consideration that this previous block again depends on the hash value of its respective predecessor, it becomes evident that each given block directly depends on the hash values of every other block before.

Tamper proof:
The concept explained in the paragraph above also implies that once data is stored on the blockchain it becomes permanent and tamper proof, as any change in a blocks data would alter its hash value, thus altering the hash values of every subsequent block (including the most current).

Consensus mechanism:
Whenever new information is added, the blockchain’s algorithm tries to ensure that only valid blocks containing valid transactions and valid block headers are added to the blockchain. The computers that verify transactions are called miners. To ensure that the information to be added to the blockchain is correct, the algorithm requires a majority of miners to agree on information. This process is called the consensus mechanism. Of course, no one would willingly verify information without having some incentive, thus miners are usually rewarded with tokens. In case of the bitcoin blockchain, the incentive comes in the form of bitcoins (Drescher, 2017).

Proof of work:
As mentioned before, if a block is to be added to the blockchain, all nodes must agree on its validity (consensus mechanism). This process is called mining, and the participating nodes are called miners. But what prevents a miner from proposing thousands of inaccurate transactions, hoping that eventually the network will validate one of his or her inaccurate transactions. Proof of work purposely makes the process of proposing new blocks to the network expensive. Only the miner to first successfully solve an extremely difficult calculation can propose a new block. Since it is more than likely that a block containing false information will be rejected by the network anyway, the miner would only waste computing power when trying to add false transactions to the blockchain (BitFury Group, 2015).

Proof of stake:
In addition to proof of work, proof of stake is another approach to ensure the blockchain’s integrity. Nodes participating in the proof of work mechanism are called validators and can be regarded as the equivalent to miners within a proof of work mechanism. Here, the validator that gets to add the block to the blockchain is chosen randomly out of a pool of validators that all have tokens from the specific blockchain. If a validator is chosen to add the new block, the system will freeze some of the validators tokens before the block is added. These tokens will only be returned once the network has agreed that the block is valid. The deposit system thus creates an incentive for validators to only add valid blocks (BitFury Group, 2015).

4.3 The Current State of Blockchain Technology
Like with most other technologies, the blockchain’s capabilities are constantly being improved. Although there is no common consensus in literature, most experts typically categorize blockchains into two generations:
4. The Underlying Technology

4.3.1 First generation blockchains

The appearance of bitcoin in 2008 marked the invention of the blockchain, and bitcoin as a digital currency was the first use case of the technology. By making bitcoin’s code open source, the creators behind bitcoin allowed development teams all over the world to create a variety of new blockchains, all mimicking and expanding on the bitcoin blockchain’s underlying idea and code. Thus, all first generation blockchains were decentralized virtual currencies, which essentially means they record transactions and keep a public ledger of them. Some examples include Litecoin, Monero, Dash and many more (“Blockchain Generations: Cryptocurrencies, Blockchain Platforms, Decentralized World,” 2018).

4.3.2 Second generation blockchains

The success of first generation blockchains in form of virtual currencies made IT experts think about the greater potential of the distributed ledger technology. In 2013, Russian programmer Vitalik Buterin proposed the idea of not only recording transactions on a blockchain, but also incorporating programming language onto the blockchain. He proposed the idea of smart contracts, which at its core are small, self-executing computer programs run on a blockchain. Smart contracts became the basis for Buterin’s blockchain platform Ethereum.

4.4 Limitations of Blockchain Technology

The following chapter aims to describe where and why blockchain technologies have their limitations.

4.4.1 Current technical challenges

Below aspects have been identified as some of the most important technical limitations of the blockchain technology:

Security:

Although the cryptography itself used in the blockchain is considered extremely secure, it does not protect the owners from accidentally revealing their private keys or having them stolen. This private key is the only security instrument authorizing the lawful owner. Once another person has gotten access to the private key, the security is broken (Drescher, 2017).

Another security issue is the possibility of a 51-percent attack. In this scenario, a single mining pool provides more than half of the system’s computational power. This single mining pool would then be able to record false information on the blockchain. However, in reality this is only relevant to new blockchains, as once a given blockchain has reached a larger number of participants (critical mass), a 51-percent attack becomes virtually impossible (Drescher, 2017).

Limited scalability:

Blockchains such as Bitcoin or Ethereum rely on a consensus mechanism amongst nodes whenever new blocks are added. This ensures that the history of transaction data is protected from being manipulated or forged. However, this is also what limits the blockchain’s throughput, or total number of transactions per second (tps) the blockchain can process (Drescher, 2017). In case of the bitcoin blockchain, the transaction speed is limited to around 7 tps. To put this number into perspective, the VISA network can reach up to 10,000 tps, and Twitter even has a maximum of around 15,000 tps (Swan, 2015).
4. The Underlying Technology

High costs:
Most blockchains use a proof of work consensus mechanism (chapter 4.2.2) to ensure the blockchain’s integrity. This mechanism relies on solving computational hash puzzles which requires large amounts of computer power, which in return leads to high costs in form electricity (Drescher, 2017).

Hidden centrality:
Although any computer could, in theory, use its computational power to become a miner, the reality looks different. As hash puzzles are required to increase in difficulty, most of the mining in mature blockchains is done by a few, highly specialized entities with vast amounts of computational power, and are usually located in areas with access to cheap electricity. These groups could eventually form an oligopoly, thus undermining the distributed nature of the blockchain (Drescher, 2017).

4.4.2 Nontechnical limitations

Lack of legal framework:
As with most innovations, the supporting legal and regulatory frameworks often lack behind the technology. In case of the blockchain, many questions regarding the legal implications and acceptance of transactions are yet to be discussed. Many compare the blockchain’s legal status today to the lacking legal acceptance of internet commerce in the 1990s (Drescher, 2017).

Intermediaries feeling threatened:
One of the blockchain’s main advantages is its ability to disintermediate processes that would normally require a third party to become involved (further explained in chapter 7.1.1). An example could be the entire process of patent registration, where many intermediaries (e.g. notaries, lawyers, patent offices) are involved, making the entire process extremely bureaucratic. Storing patents on a blockchain could potentially make some of them, or at least part of their work obsolete. Those intermediaries could become threatened in their existence and might try their best to retain the status quo. Another prime example could be the banking industry, which makes substantial parts of its income by charging transactions fees. Especially when sending money to another country, these fees could be very high. Cryptocurrencies allow the exchange of value directly between peers and without the need of intermediaries in the form of banks. This, of course, poses a threat to their existing business model.

Lack of user acceptance:
The still very much open legal status of the blockchain can cause uncertainty amongst users, which in return can reduce their interest in the technology. The uncertainty on where the development of the blockchain technology is headed causes further uncertainty amongst users, thus further decreasing their interest (Drescher, 2017).

Price speculations:
Most blockchains are using some sort of token-system to incentivize and reward miners (chapter 4.2.2 “consensus mechanism”). However, many of these tokens are subject to price speculations and often see daily price fluctuations of up to 10% or more. Thus, projects based on public blockchains are presented with great levels of uncertainty (Fauvel, 2017).
5. Theoretical Analysis

The following chapter will present theoretical background information, as well as a theoretical analysis on how the blockchain technology fits into innovation theory.

5.1 Defining Innovation

Austrian economist Joseph Schumpeter, seen by many as the most important economic thinker of the first half of the 20th century, was amongst the first to define the term ‘innovation’. In his 1939 book *Business Cycles* he describes innovation as the creation of a new production function. He explains that a new production function could be the result of a new product, the exploration of new markets, as well as changes within the organizational structure (Schumpeter, 1939).

5.2 Technology Adoption

The following will explain how new technologies are adopted in their respective markets, as well as analyze the degree to which blockchain-technology has been adapted.

5.2.1 The diffusion of innovation theory

According to Everett M. Rogers’ *diffusion of innovation theory* (1962), the adoption of a given innovation within a social system occurs at different times. Rogers describes a social system as “a set of interrelated units that are engaged in joint problem solving to accomplish a common goal” (Rogers, 1962, p. 24). Members of this social system could be individuals, informal groups, or in this case organizations. He went on to divide the population within the social system into five different groups, consisting of innovators, early adopters, early majority, late majority, and laggards.

*Innovators*, which account for around 2.5 % of the total population, are the very first to adopt a new technology. They are willing to take risks, have sufficient financial backing, and usually know a lot about the technology.

The second group that adopts the technology are the *early adopters* (13.5 %). They are people that use new technologies significantly earlier than the majority. Early adopters can act as ambassadors of the new technology and form opinions amongst the majority of users.

The next 34 % are called the *early majority*. They consist of everyone who adopts the technology after the early adopters, but before the half-way point of adoption is reached.

Like the early majority, *the late majority* accounts for 34 % of the population. However, the late majority consists of people that adopt a technology after the average consumer does. Compared with the early majority those people often are more skeptical and/or have a lower income. Often, they must first be convinced or pressured to adopt.

The last group to adopt a technology are called *laggards*. They account for 16 % of the overall population, and are the last to adopt. Laggards are often averse to change and focused on traditions. By the time they adopt a technology, innovators might have often already moved on to a new technology.

When visualized, the diffusion of innovation curve often takes the shape of a bell curve (*Figure 4*).
5. Theoretical Analysis

5.2.2 The current state of blockchain technology adoption

In order to assess the blockchain technology along the diffusion of innovation adoption curve, Wodside et al. (2017) took a triangulation approach. They tried to assess the technologies adoption by comparing the result of three different analysis (an environmental analysis, a text analysis, and a financial analysis).

Environmental analysis:
The environmental analysis, where they evaluated the technologies political-, economic-, social-, and technical environment, determined that that blockchain technology is on its way to the early adopters category. What currently prevents the blockchain from advancing to the early adopters category is an ongoing competition between different blockchain technologies, as well as the uncertainty around global governmental regulation. As a result, the study found that blockchain still resides in the innovators category, or the first 2.5 % of total adoption.

Text analysis:
The text analysis, where annual reports were scanned for the word ‘blockchain’ and other blockchain-related keywords, found that by the time of the study in 2017, only one company out of 50 (IBM) had specifically mentioned the blockchain in their annual report. Compared with other mega-trends, such as artificial intelligence, internet of things, cloud computing, or augmented reality, blockchain ranked last in the text analysis. Thus, the text analysis also places blockchain technology in the innovators category.

Financial analysis:
The financial analysis, which examined financial investments in the technology, stated that $1.4 billion were invested in blockchain startups in 2016. It was also mentioned that the big four accounting firms (EY, PwC, Deloitte, KPMG) are heavily researching and investing in the technology. At the time of the study, the US Dollar value of all cryptocurrencies combined had a value of $91.073 billion, which would be equal around 5.8 % of the total US Dollar currency in circulation. Due to substantial price increases
on the crypto currency market, the financial analysis finds blockchain to have partly moved to early adopter category.

Results and conclusion:
As a result, the study found that the blockchain technology is mostly seen within the innovators category, or the first 2.5% of market share. However, the study also acknowledges that blockchain is not far from reaching the early adopters category, with financial applications having partly reached the early adopters category already.

The authors conclude that blockchain technology brings the potential to disrupt and innovate many key areas of business. However, they state that the accounting industry will be impacted the most as the blockchain could automate many of its manual processes, such as the labor intensive double entry book keeping process.

5.2.3 The s-curve profile of technology adoption
The rate in which diffusion takes place can be described by an s-curve. It shows that the rate of adoption over time is rather slow at the beginning of the diffusion process (innovators and early adopters), accelerates towards the middle (early- and late majority), and again slows down towards the end of adoption (laggards). This s-curve is the derivative of the diffusion bell-curve (Figure 4).

5.2.4 Critique
Rogers’ diffusion of innovation theory can play a key role in understanding how a technology is being adopted. However, the theory also has its limitations.

First of all, Rogers’ diffusion theory assumes that the technology itself is static and does not change within its lifecycle (Adner & Kapoor, 2015). As technologies undergo constant progress, it can be argued that Rogers’ static view on technology is not entirely correct. For example, rapid or unexpected improvements could speed up the adoption process. Furthermore, not only does the new technology undergo change, but also the old technology which is being replaced.

The diffusion of innovation theory further does not take the technology’s ecosystem into account. However, both new- and old technology depend on their respective ecosystems. Emergence challenges for the new technology could arise due to problems within the technology’s ecosystem, while the old technology’s ecosystem could provide extension opportunities (Adner & Kapoor, 2015).

5.3 Technology Improvement
In the 1980’s, Richard Foster examined the nature of technology improvements and helped to explain how technology is substituted. Amongst others, he came up with the following principles.

5.3.1 The s-curve of technology improvement
The s-curve of technology improvement describes the basic pattern of technological change in three phases.

It shows how performance improvements achieved through a given amount of effort or time are relatively small in the early development stages of the technology, hence making the curve appear relatively flat. This phase is called infancy (Figure 5 – I).

However, as the technology becomes better understood, the rate of progress increases and substantial improvements in performance can be achieved with relatively little effort. This phase is called explosion (Figure 5 – II), and the curve itself follows a relatively steep pattern.
As the technology matures, improving the technology will become increasingly difficult and improvements themselves more and more incremental which results in decreasing returns. This phase, which is called gradual maturation (Figure 5 – III), depicts an increasingly flat curve (Foster, 1986).

5.3.2 Discontinuity

Once a given technology approaches the top of its s-curve, meaning it has reached its limits, a new technological concept needs to emerge in order to ensure further technological progress. This transition usually is not smooth, and results in a phase where both technological concepts compete with one another (Figure 6). This phase in which the new technological concept gradually substitutes the old technology is referred to as discontinuity (Foster, 1986).
5. Theoretical Analysis

5.3.3 Critique

Foster’s ideas of technology improvement and the s-curve of technology improvement lack in the following aspects.

For one, Foster’s theories assume that the technology s-curve of the old technology will eventually flatten, and no further progress is made. This however, often does not hold true and sometimes improvements in the old technology can still be achieved. Adner et al. (Adner & Kapoor, 2015, p. 17) found that “at times, the pace of substitution was slowed due to “last gasp” efforts by some firms to maximize the value that they could capture from the old technology”.

Furthermore, the role of demand-side adoption is mostly overlooked. Therefore, the question when dominance over the old technology will be achieved is ignored, and the wrong assumption is made that the better technology will always take over the market (Adner & Kapoor, 2015).

5.4 Analyzing the Pace of Technology Substitution

While the technology adoption literature (e.g. Rogers, chapter 5.2) has examined the rate of technology adoption but ignored that fact that both old- and new technologies as well as their ecosystems continue to evolve, literature regarding technology improvement (e.g. Foster, chapter 5.3) mostly overlooks demand-side adoption and therefore does not give much information about when dominance will be achieved (Adner & Kapoor, 2015).

Adner and Kapoor (2015) argue that in order to truly understand the pace of technology substitution and its dynamics, the concepts of technology adoption and technology evolution need to be linked. Furthermore, they recognize that technology substitution does not solely depend on the two technologies in question but should rather be seen as a competition between the new- and old technology’s ecosystems. While the old technology’s ecosystem could delay substitution by offering extension opportunities for the old technology, emergence challenges within the new technology’s ecosystem could also delay substitution (Figure 7). This is what results in a difference between the theoretically possible technical performance of the technology, and the actual realized performance.

Figure 7. Technology competition between an old technology with consideration of their respective ecosystems according to Adner & Kapoor (source: Adner & Kapoor, 2015, p. 5)
Acknowledging this, Adner & Kapoor developed a framework for analyzing the pace of technology substitution, which takes both, technology adoption and evolution, as well as both technologies’ respective ecosystems into account. The result is a matrix that considers the emergence challenge of the new technology on the one axis, and the extension opportunity of the old technology on the other axis (Figure 8).

Quadrant 1 - Creative destruction:
Quickest substitution can be expected in situation with low emergence challenges and low extension opportunities. Here, the old technology has little potential respond to the threat, while the new technology’s potential is not held back by bottlenecks elsewhere in its ecosystem (Adner & Kapoor, 2016).

Quadrant 2 - Robust coexistence:
Low ecosystem emergence challenges for the new technology, but high ecosystem extension opportunities will result in an ongoing competition between the technologies. Although the new technology will be able to gain access to the market, but improvements in the old technology ecosystem will allow it to defend some of its market share (Adner & Kapoor, 2016). This results in a prolonged period of coexistence before substitution takes place, which can be quite beneficial for the consumer as ongoing competition can improve the performance of both ecosystems (Adner & Kapoor, 2015).

Quadrant 3 - Illusion of resilience:
High ecosystem emergence challenges for the new technology and little ecosystem extension opportunity for the old technology will result in a period of stagnation until the emergence challenges can be resolved. This period will most likely leave the old technology with a relatively high market share but little growth. The old technology’s high market share must be seen as very fragile, because once
the emergence challenges for the new technology can be resolved, substitution will be rapid (Adner & Kapoor, 2016).

5.5 Assessment Along the Gartner Hype Cycle

In order to correctly examine potential applications of the blockchain technology and predict future developments, it is important to first determine and understand the current phase of the technology.

Figure 9. Garner hype cycle (source: Gartner Research, 2013, p. 15)

The Gartner Hype Cycle is a commonly used tool to determine the phase of a given technology. Developed by the information technology firm Gartner Inc., it allows to visualize the expectations in a technology over time since it emerged. It is based on the assumption that all new technologies follow a universal pattern and can be divided into distinct phases. After the technology is first triggered through a technology breakthrough (Innovation Trigger) expectations tend to rise quickly due to hype and initial success stories. This sharp increase in expectations continues until the Peak of Inflated Expectations is reached. Once it becomes evident that the technology will not, or not yet live up to the inflated expectations, it is rapidly discredited and sent into the Through of Disillusionment. As second- and third-generation products are being launched, the technology begins to climb towards the early stages of maturity. This phase is called the Slope of Enlightenment. It brings the technology all the way to the Plateau of Productivity, which represents the beginning of mainstream adoption (Gartner Research, 2013).

A 2017 study (Dieterich et al., 2017) found that, at the time, most experts saw the technology either right on top the Peak of Inflated Expectations or on its way towards it (Figure 10). These further stresses the importance of distinguishing between hype and valuable potential use-cases in each industry. It must be noted, however, that the results depicted in the survey have been gathered prior to November 2017. Combined with enormous price decreases in cryptocurrencies within the first half of 2018, it can be assumed that the technology has now already passed the Peak of Inflated Expectations and is advancing towards the Through of Disillusionment.
6. Blockchain – A Foundational Technology

It is often heard that the blockchain technology will revolutionize various areas of business. Although most experts realize the technology’s potential, many do not share the ongoing hype. Apart from the technology’s many technical- and nontechnical limitation (chapter 4.4) that are yet to be resolved, blockchain-led transformation of business and government will take its time due to blockchain not being a disruptive technology, but rather a foundational technology (Iansiti & Lakhani, 2017). Instead of attacking traditional business models and quickly overtaking them through a better and/or cheaper solution as disruptive technologies do, a foundational technology has the potential to create new foundations for the entire economic- and social system. And although a new foundational technology usually has an enormous impact, it often takes decades for the technology to unfold its potential. The adoption process (chapter 5.2) of foundational technologies thus is not sudden, but more gradual and steady, slowly gaining momentum with every technological improvement or institutional change.

6.1 Adoption Status of Foundational Technologies

Iansiti & Lakhani found that the adoption of foundational technologies can be defined along two dimensions. These two dimensions help to determine how fast a foundational technology’s different use cases will be adopted.

Novelty, the first dimension, describes how new the use case is to its target group. Applications with a high degree of novelty are relatively unknown to users. This means that greater efforts will be required to make sure that people understand and appreciate the value the application creates.

The second dimension is complexity, which is represented by the level of ecosystem coordination required to make the specific application possible.

6.2 Adoption Matrix for Foundational Technologies

Evaluating a foundational technology and its use cases along the two dimensions described in chapter 6.1 creates four quadrants or categories. To make their ideas more tangible, Iansiti & Lakhani applied their framework to the TCP/IP technology as an example. They have also given possible blockchain applications that could represent each category (Figure 11).

TCP/IP (transmission control protocol/internet protocol) is the technology behind the internet, and introduced a completely new way of transmitting information. It can be seen as a prime example for a foundational technology (Iansiti & Lakhani, 2017). Although the technology was already introduced in 1972, it took years for different use cases to be developed and adopted. E-mail, the World Wide Web, or Voice Over IP are only a few of many different use cases the technology made possible, and all emerged at different times.

Single use:
This first quadrant consists of applications low in both, novelty and coordination. These applications are usually relatively simple, but present a better, cheaper, and highly focused solution. In the case of TCP/IP, early e-mails between university researchers within the Advanced Research Project Agency Network (the birthplace of the internet) in the early 70’s would fall into this category (Kleinrock, 2010). For the researches e-mail was a single-use application that presented a cheap alternative to phone calls, faxes and mail (Iansiti & Lakhani, 2017).
6. Blockchain – A Foundational Technology

Localization:
Despite being high in novelty, solutions in this second quadrant are relatively low in complexity. This makes promoting their adoption quite simple. A use case within the TCP/IP technology that falls into this category is the adoption of network technologies by organization as they started to create their own e-mail network systems (Iansiti & Lakhani, 2017).

Substitution:
In this third quadrant, solutions are relatively low in novelty as they build on existing single use and localization use cases. However, coordination becomes complex as solutions within this category have a broader and more public use. They aim to replace entire business concepts, thus facing high adoption barriers. Amazon’s early days as an online book store, trying to change the process of how people purchase books, would be a perfect example of a use case from this category (Iansiti & Lakhani, 2017).

Transformation:
Solutions within this fourth quadrant are completely new and very high in complexity. They require coordinating the activities of many actors, as well as institutional agreement on standards and processes. Adoption will depend on major social, legal, and political change. However, if successful these solutions could change the nature of economic, social, and political systems (Iansiti & Lakhani, 2017). In the case of TCP/IP technology, video conference technologies (e.g. Skype), which could result in a shift towards virtual-, and away from in-person meetings, can be seen as an example for this category.

![Figure 11. Adoption of foundational technologies](source: own representation based on Iansiti & Lakhani, 2017)
Different Applications of Blockchain Technology

7. Different Applications of Blockchain Technology

7.1 Environments in which Blockchain is Useful

To better understand which blockchain applications we might see in the future, it makes sense to first have a look at the advantages and limitations of the technology, as well as examining which environments the technology is suited for best.

7.1.1 Advantages of blockchain technology

Amongst others, literature describes the following aspects as the main advantages of blockchain technology.

Disintermediation:

Disintermediation is being named as one of the most important long-term impacts of the blockchain. Drescher (2017) describes the blockchain as a digital and strictly rule-following middleman, which bears the potential to, at least partly, replace traditional middlemen such as banks, notaries, or legal institutions. This means that middlemen in form of human organizations, which rely on the trust of their customers, could be replaced with software systems that ensure trust via code. Furthermore, secure and direct transactions between peers can not only make one, but potentially many traditional middlemen obsolete.

Decentralization:

Although there might be different opinions on whether the blockchain’s ability to decentralize information can always be regarded as an advantage or not, it definitely is one of the very key attributes of the technology. With blockchain there is no need for central data hubs (data centers), because transactions can now proof their validity themselves (Williams, 2017).

Automation:

The blockchain has the potential to replace manual tasks, which have previously been carried out by intermediaries, with automated interactions between peers. Therefore, the argument can be made that blockchain fosters automation (Drescher, 2017).

Increased transparency:

The use of blockchain technology can make transaction histories far more transparent than they are right now. As discussed previously, the blockchain can be considered a form of distributed ledger, with all network participants sharing the same documentation instead of each having individual copies. This shared documentation can only be updated once all participants have agreed on it (consensus), making documentation on the blockchain more accurate, consistent and transparent (Hooper, 2018).

Improved traceability:

Greater transparency of transactions also results in better traceability of products. For example, exchanges of goods can be recorded on a blockchain, leaving behind a tamper proof audit trail of historical transaction data which can proof authenticity of the product and prevent fraud (Hooper, 2018).

Enhanced security:

When compared to centralized record-keeping mechanisms, the blockchain provides better security by preventing fraud and unauthorized activity. This is due to transactions having the be agreed upon before recording them, their subsequent encryption, as well as them being linked to all previous transactions. Furthermore, information is not stored on a single server, but an entire network of computers.
This makes it far more difficult to (purposely or accidentally) damage or alter sensitive data (Hooper, 2018).

**Increased efficiency and speed:**
Traditional processes heavily rely on paper work, are prone to human error, and often require third-party involvement. These factors make many, especially inter-organizational, processes inefficient and time-consuming. The blockchain promises to address many of these factors, thus increasing the efficiency and speed of various processes (Hooper, 2018).

**Reduced costs:**
Besides cost reductions through automation, blockchain can especially cut costs through disintermediation. The use of blockchain allows for fewer third party involvement as guarantees and legal protection provided by various middleman can be replaced by inherent trust in the data stored on the blockchain (Drescher, 2017). Furthermore, there will be less need to review documentation before trades, as the blockchain ensures that all parties have access to the very same, immutable version of a given document (Hooper, 2018).

### 7.1.2 Environments in which blockchain technology could be beneficial

A 2016 paper released by PricewaterhouseCoopers (PwC, 2016) identified six distinct characteristics that would support the use of blockchain. The company suggested that for every situation where at least four out of the following six examples apply, blockchain solutions could be a valuable solution.

1. Multiple parties share data and need a common view of data
2. Multiple parties update data and these actions need to be recorded
3. Participants need to trust that the actions that are recorded are verified as valid
4. Intermediaries add cost and complexity
5. Interactions are time sensitive, with delays adding costs
6. Transactions created by participants are depended on each other

### 7.1.3 Generic blockchain applications

Based on the technology’s characteristics, Drescher (2017) describes seven different generic use cases for blockchain.

1. **Proof of existence:**
   The blockchain can help to prove the existence of data. Once data is stored on the blockchain, every node within the network can confirm the very existence of the data. This use case becomes more obvious when looking at concrete examples like registries of items such as brand names, patents, license codes, or internet addresses.

2. **Proof of nonexistence:**
   Contrary to the example above, this use case provides a way of proving the nonexistence of specific entries or items on the blockchain. Examples could be proving that a person or company has no record of complaints, fines, or convictions.

3. **Proof of time:**
   As every block also contains a time-stamp (chapter 4.2.2), the blockchain cannot only prove an entry’s very existence/nonexistence, but also the exact time and date the entry was added. Applications that could benefit are, for example, the tracking of payments, delivery or notification tracking, the management of predictions, etc.
4. **Proof of order:**
   Apart from stating the exact time of an event, the blockchain also clearly proves the relative order in which events occurred. Proving that a certain event took place before another event could be used in examples such as patent applications or copyright claims.

5. **Proof of identity:**
   As a specific case of proof of existence, proof of identity can ensure that a certain identity already exists. This could be used in the form of digital identity documents for people, animals, or goods, similar to a forgery-proof paper document.

6. **Proof of authorship:**
   The blockchain can also provide information on who added certain data. Through the concepts of identification and authentication require authors to verify their identity before making an entry on the blockchain. A very good example for this use case could be the tracking of content changes in documents.

7. **Proof of ownership:**
   Relying on all previously mentioned use cases, this pattern allows to manage and clarify ownership of real estate, cars, company shares, cryptographic currencies, and many more.

### 7.2 Overview of Blockchain Use Cases across different Industries

Being a foundational technology (chapter 6), the blockchain could potentially find use in hundreds of different use cases, many of whom are probably not even known today. The following sub-chapter aims to give the reader an idea of where the blockchain could be used. It therefore must be noted that the following does not present a complete list of possible applications, but rather a few chosen examples.

#### 7.2.1 Banking

With cryptocurrencies being the very first applications of the blockchain technology, the banking- and financial industry has naturally been a pioneering sector for blockchain. According to a 2016 survey by IBM, 91% of banks have planned to invest in blockchain solutions by 2018 (Bear et al., 2016).

**Solving the double spending problem:**

The double spending problem describes the risk that digital currencies could potentially be spent twice. In contrast to physical currencies, where in order for one person to receive a payment the other person has to hand over the physical coin or note, digital currencies consist of digital information. Since digital information can easily be reproduced, digital currencies require someone to ensure that whatever amount transferred from one account to another is not only accredited to the receiving account, but also deducted from the senders account. In today’s fiat systems, this is ensured by intermediaries in the form of banks. Cryptocurrencies such as bitcoin effectively solve the double spending problem by maintaining a shared public transaction ledger. This means that funds can only be credited to one account if they are being debited from another account at the very same time, similar to how for one person to receive a coin another person has to let go of it (“Double-Spending Definition | Investopedia.”).

#### 7.2.2 Insurance

Within the insurance industry, the blockchain technology could potentially enable new revenue models. For example, Gatteschi et al. (2018) describe how the emergence of smart contracts and blockchain based payments could enable micro- or pay-per-use insurances. Although theoretically possible, these types of insurance were not economically feasible in the past as they usually were not able to cover the administrative costs associated with them. The use of smart contracts, for example, could allow
quick and cheap policy undersignment and management on mobile devices with close to no waiting time.

7.2.3 Energy markets
The blockchain is said to help establish decentralized energy markets by, for example, allowing energy sources and consumers to automatically trade energy without having to rely on intermediaries. Here, inputs like amount of energy produced by a device can be recorded on the blockchain’s public ledger, while smart contracts can sell the stored energy to consumers (e.g. smart homes) willing to pay a certain price (Martyniuk, 2018).

In late 2017, Siemens has doubled down on its investment in New York based microgrid provider LO3 Energy, who has developed a blockchain based platform for microgrids. The company’s platform allows solar panel owners to directly trade unused solar energy with their neighbors. Saving and timestamping every transaction on the blockchain keeps an immutable record of who sold which amount of energy to who, while token-based payment systems allow for real time transaction settlements (Siemens AG, 2017).

7.2.4 Retail & consumer goods
The blockchain is also said to have a great impact on retail- and consumer markets mostly through its potential to make supply chains more visible and trustworthy.

Product origin:
As the blockchain makes a product’s supply chain far more transparent, product information can be made more accessible to consumers. Walmart, for example, once conducted a traceback test on mangos prior to using blockchain. It took them almost seven days to trace the mangos back to the original farm. With the help of a blockchain-backed supply chain, Walmart was able to provide the same information in 2.2 seconds (Charleboris, 2017).

Food safety:
Integrating blockchain based solutions into food supply chains not only helps to understand where the product is coming from, it can also help to ensure food safety along the way. ZetoChain, for example, is aiming to provide an end-to-end solution for not only recording the products origin, but also monitoring environmental data such as temperature along the its journey. This is achieved by using blockchain-enabled IoT temperature sensors placed at every link in the cold chain, as well as the use of smart contracts that prevent the acceptance of a specific delivery should sensors record an interruption in the product cold chain (Zeto, 2018).

7.2.5 Public sector
Blockchain solutions could play a vital role in various governmental processes. Many governments, including the UK, Brazil, China, Sweden and the US are already running pilots, tests, and trials on different blockchain-based applications (Killmeyer, White, & Chew, 2017). Some examples of potential applications in the public sector are presented in the following.

Identity management:
Linking the physical- and digital world requires a digital identity and since more and more processes take place online people have to create more and more digital identities. There are digital identities at banks, insurance companies, tax agencies, healthcare providers and many more. As of right now, our digital data is stored on a variety of different databases and generated at different times, which results in the problem of not all digital identities being identical and up to date. The Blockchain allows a person
to create one single digital identity that is stored in a secure and incorruptible manner, and which can be used for a variety of online activities that require a person’s identification. The government of Estonia, for example, has already established a blockchain-based digital ID that can be used to vote, file tax reports, open bank accounts, register property, and many other activities that involve a person’s identification (Shaan, 2018).

Property registration:
Today, land- and property registration is a mostly paper-based and fragmented process, which makes transactions costly, inefficient, and vulnerable to tampering. By using the blockchain, a decentralized, standardized and non-corruptible record keeping system for property registration could be established. This system would reduce the number of intermediaries required (e.g. notaries), strengthen property rights, and decrease process time and cost (Killmeyer et al., 2017).

Voting:
Similar to how people can initiate other secure transactions, the blockchain can allow citizens to cast and validate votes, as well as verify election results. A blockchain based voting process promises to greatly reduce costs (e.g. ballot printing, electronic voting machines, maintenance, etc.), increase security and auditability of votes, allow all citizens to vote from anywhere in the world (Killmeyer et al., 2017).

7.2.6 Healthcare
One of four promising potential blockchain applications in healthcare identified by BCG in 2016 (Close et al., 2016), is to record a patients individual medical record on a blockchain. This would allow patients to use public and private keys to license data access to doctors, hospitals, or other parties with whom the patient would like to share his or her medical records. Having medical records stored on a blockchain would not only give those who have been granted access by the patient a complete medical history of the patient, but also provide the patient with a complete audit trail of every doctor, healthcare provider, medical device, or other entity that has had access to the his or her health care records. Britain’s National Health Service (NHS) is collaborating with Google’s DeepMind to create a private blockchain that would enable patients to track personal data access and use in real time.

7.2.7 Automotive
Blockchain is also making its way into the automotive sector. Car manufacturers, such as Toyota, BMW, Volkswagen, or Renault have announced initiatives to bring blockchain to the automotive sector (McIntosh, 2018).

Maintenance- & sale history:
Blockchains could play a key role in keeping track of a car’s maintenance and sale history, giving car dealers, part manufacturers, and customers more transparent and reliable information about the vehicles history. The company BigChainDB is working on the ‘CarPass’ platform, which aims to give each vehicle an immutable digital passport.

Similarly, car manufacturers could be able to track individual parts, enabling them to know exactly which vehicle they went into. Knowing exactly which parts went into a specific car becomes valuable when certain parts need to be recalled, as manufacturer would be able to only recall those vehicles that were actually fitted with the problematic part (McIntosh, 2018).
7. Different Applications of Blockchain Technology

Autonomous driving:
According to German automotive supplier ZF Friedrichshafen, artificial intelligence and blockchain based transactions must be combined when it comes to autonomous driving. Self-driving vehicles not only need to drive, but also need to be able to perform transactions and payments. In cooperation with IBM and UBS, the company has therefore developed a ‘Car eWallet’ based on blockchain technology that will allow cars to make autonomous on-the-go payments themselves. This capability would allow cars to autonomously transact with power charging stations, and will be of special importance in regards to car-sharing and pay-per-use models (ZF Friedrichshafen AG, 2018).

According to Jim Milan, blockchain could also play an important role in mitigating the risk of hacking attacks on autonomous vehicle fleets. Milan states that instead of having all connected cars report to a single server, blockchain would distribute the data amongst all network participants. Hacking the system would now require hacking all vehicles on the network simultaneously, instead of attacking a single server (Mcintosh, 2018).

7.2.8 Entertainment
Today, platforms such as YouTube, Spotify, Netflix, or SoundCloud act as distributors for video and music content. This model has led to various payment disputes between artists (most famously Taylor Swift) and platforms. Blockchain promises to enable new business models in the entertainment industry (Dhillon, 2018).

Micropayments:
By making micropayments economically feasible, blockchain could allow artists and content creators to sell content directly to consumers, potentially eliminating the need for intermediaries such as record labels or streaming providers. In theory, artist could enjoy full control over how they are paid and in which way their content is monetized. Users could directly buy licenses to download, stream, remix, or use a piece of content (e.g. a song) from the creator (Dhillon, 2018).

Digital rights:
Blockchain can also help securing rights and authorship for any kind of digital content. Digital rights management startup Mediachain, which has recently been acquired by Spotify, is working on a solution where digital content is given a unique ID which is then securely manifested on the blockchain, creating a media library where author and story behind every piece of content can be identified (Dhillon, 2018).
8. Blockchain in Manufacturing

A 2016 survey by Deloitte found that executives within the manufacturing industry had amongst the most optimistic outlook on blockchain, with 42% of participants stating that substantial investments were already being planned for 2017 (Schatsky & Piscini, 2016). Despite its optimistic position, the manufacturing industry still has a long way to go in terms of blockchain adoption when compared to the financial industry (Iansiti & Lakhani, 2017).

Being a foundational technology (chapter 6), the blockchain could potentially affect the manufacturing industry in a variety of ways. However, experts such as Dieterich et al. (2017), identify three main categories of how the blockchain could transform manufacturing.

8.1 Supply chain and logistics
Supply chain and logistics is said to be one of areas where blockchain could unfold its greatest potential. IBM and Dutch logistic giant Maersk were amongst the first to develop a blockchain based platform to help track the paper trails of thousands of shipping containers around the globe. Instead of having bits of information spread amongst different entities within the supply chain, the blockchain can essentially provide a shared visibility ledger, everyone within the supply chain reports to. Although solutions using traditional software do exist, they are usually owned by one entity and thus not interoperable along entire supply chains. Being open standard, blockchain initiatives will allow different systems to be integrated into the supply chain ‘network of networks’ (IBM, 2017).

Potential benefits of blockchain based supply chains include:

Increased traceability:
Blockchain enables more transparent and accurate end-to-end tracking of materials along the entire supply chain. This helps companies to ensure that quality-, as well as other corporate standards such as social responsibility are met, especially since transaction records essentially become immutable once recorded on the blockchain (Deloitte, 2017).

The company Everledger, for example, has created a blockchain based platform that lets jewelers track exactly which mine a given diamond came from. This helps them to ensure that mining and transport of diamonds has been in line with ethical standards (“Everledger Diamond Platform,” n.d.).

Decreased losses from counterfeit:
Knowing exactly how parts and finished goods are passed through the chain of subcontractors could help prevent losses from counterfeit and gray market trading, as well as increase confidence for end-market users (Deloitte, 2017).

Improved visibility:
The blockchain could ensure that every authorized party within the supply chain will have access to the very same documents and information. By reducing communication or data errors less time needs to be spent validating information, which in return speeds up the process and saves costs (Deloitte, 2017).

Reduced administrative costs:
Having instant access to complete and audit proof supply chain data helps to reduce costs by accelerating administrative processes for compliance or credit purposes (Deloitte, 2017).
8. Blockchain in Manufacturing

8.2 Internet of Things (IoT)

Connecting physical devises and allowing them to collect and exchange data on the network is said to be one of the key drivers of industrial growths over the coming years. The Internet of Things (IoT), or Industrial Internet of Things (IIoT) as it is referred to in an industrial setting, will help companies to capture growth by increasing production rates and efficiency, creating new hybrid business models, foster innovation through intelligent technologies, and transform their workforce (Daugherty et al., 2015).

The blockchain could play an important role in future IoT applications and is said to improve current IoT solutions in different ways.

8.2.1 Improved security

As of right now, IoT devices within a network communicate through intermediaries in the form of central cloud servers. This makes IoT systems prone to hacking as a ‘single point of failure’ could give hackers access to the network. The distributed nature of blockchain protects networks by eliminates this single point of failure, while encryption protects individual devices from attacks (Deloitte, 2018).

8.2.2 Identifying IoT devices

Another problem the blockchain could solve for IoT systems is the identification and authentication of individual devices, which is currently achieved through certificates from third party authorities. Third party certification, however, comes with costs which makes the process unfeasible for smaller or less significant devices. In contrast to traditional certificates, registering IoT devices on a blockchain to create a unique digital identity for each device furthermore allows the information about the device to be dynamically updated and complemented (Dieterich et al., 2017).

8.2.3 Network scalability

By making communication within IoT networks more secure (8.2.1) and reducing costs for the registration process (8.2.2), blockchain can help increase the scalability of IoT networks (Dieterich et al., 2017).

8.2.4 Data integrity

The blockchain’s irreversibility and the fact that every block has a tamper-proof timestamp can help increase the integrity of sensor data. The blockchain thus helps to ensure that sensor data within the industrial internet of things has not been manipulated afterwards (Dieterich et al., 2017).

8.2.5 Granting access

The blockchain could further help with the process of granting access to data that is generated by IoT devices. Owners of IoT devices could effectively sell real time sensor data to customers in direct exchange for crypto tokens (Dieterich et al., 2017).

Blockchain based IoT networks could essentially eliminate the need for centralized cloud servers to run the network. Amongst other similar projects, Bosch and Cisco Systems have founded the Trusted IoT Alliance. In collaboration with the IOTA Foundation, BNY Mellon, and a variety of blockchain start-ups, Bosch and Cisco are developing a blockchain based IoT ecosystem (Trusted IoT Alliance, 2018).
8. Blockchain in Manufacturing

8.3 3D Printing

3D printing is likely to play an important role in future manufacturing processes. Distributed manufacturing could potentially increase flexibility and shorten shipping routes. Printing specific parts on demand could significantly reduce storage costs for spare parts. The blockchain could play an important role in securing intellectual property of printing files, as well as the tracking and verifying individual parts along the supply chain.

How blockchain could help securing intellectual property of files, and how it could allow printed parts to be verified will be further explained in chapter 9.3.
9. Blockchain Applications in Research & Development

As described in chapter 1.1, one of the main objectives of this thesis was to identify and evaluate how R&D activities within the manufacturing industry could potentially benefit from blockchain technologies. In order to identify potential use cases, two approaches were followed.

The first approach was to ideate potential use cases and evaluate them for their technical feasibility, as well as their practical potential. The second approach was to look at existing use cases and ideas from other sectors and try to translate them into a R&D setting.

9.1 Defensive Publishing

The idea of defensive publishing on a blockchain combines the concept of hashing data (chapter 4.2.2) with the blockchain’s immutable nature and its ability to timestamp data (chapter 4.2.2). Although the concept was first ideated by the author, more distinct search revealed existing prototypes.

9.1.1 Idea

Through hash algorithms, any type of data can be turned into a unique numeric value of fixed length – a unique digital fingerprint of the file. Although the hash value gives no information about the actual file, identical files will always result in identical hash values.

If a hash value was to be stored on a public blockchain, everyone could see when and by whom the value was put on the blockchain. This essentially allows companies to later prove that they were in the possession of a certain document, without having to reveal the information beforehand.

9.1.2 Example

A pharmaceutical company discovered a revolutionary new drug but is not yet ready to file a patent since more test are still to be done. However, the company also has a great interest in being able to proof that they were the first to discover the drug. Disclosing their discoveries is not an option as this would give valuable information to competitors. The company decides to summarize the current state of research in a document and create a hash value from the document. They now take the hash value, store it on a public blockchain, and remember exactly which block it was stored in. As the hash value gives no information about its underlying file, no actual information will be made public. However, at any point in the future, the company could now give the very same document to a court (or some other kind of authority), tell them exactly which hash algorithm they used in the first place, and let the court hash the file once again. All that is left to do is to compare the hash value that was just created from the file the court received with the hash value the company stored on the blockchain previously. Given that the old and the new hash value are identical, this proves that at the specific point in the past, the company was in possession of the very same document.
9.1.3 Benefit

Defensive publishing on a blockchain would allow companies to convincingly proof that a given state of knowledge or a discovery was present within the company at a very specific date in the past. The major benefit is that no actual information has to be made public beforehand.

An analogy to this process could be a document that was sealed and given to a notary who holds onto to the envelope. The notary could then later confirm the exact date on which he/she received the envelope, and that the content has not been altered.

However, compared with the notary-analogy there are two major benefits. Firstly, hash values can be created from any data regardless of size or type. Secondly, in harsh contrast to expensive notary fees, storing a hash value on a blockchain comes with little to no cost. These factors result in a far greater scalability and automatability of the process. For example, it is completely plausible to store hashes of weekly or even daily versions of lab notebooks or test results on a blockchain, while having the entire process fully automated.

9.2 Securing Specifications & Change Requests on the Blockchain

Similar to the concept of Defensive Publishing (chapter 9.1), hash values of virtually any file could be stored on a blockchain. In respect to R&D, this could for example be used for product specifications and/or change requests. Although no existing solutions were to be found at the time of this study, the idea itself was transferred from the existing use case described in 9.1.

9.2.1 Example

Contractor A and engineering service provider B have just agreed on a major change request for an engineering project. They both want to be sure that from this point on forward specifications will not be changed without explicit agreement. They decide that a binding ‘version of truth’ of the document will be hashed and stored on the blockchain, with both parties also storing the file on their private servers. Towards the end of the project the contractor realizes that the engineering service provider must have forgotten a tolerance they agreed upon. Knowingly or unknowingly service provider B argues that the tolerance was never included in the specifications.

However, instead of wasting valuable time and resources on finding out which of the two parties is right, contractor A can effectively proof that their version of the document is correct by simply comparing the hash value of their document with the hash value stored on the blockchain.

It should be noted that this example could be applied to any contract or document where two or more parties have an interest in storing a trustable, tamperproof copy on neutral ground.
9.2.2 Benefit
The main benefit arising from this application is the ability to store an immutable and time-stamped ‘version of truth’ of any document on neutral ground. Again, this could also be achieved by giving a copy of the document to a trusted third party (e.g. notary) which ensures that the version it received stays unaltered. As with the previous example, scalability and high costs are the main disadvantages compared to the blockchain alternative.

Another benefit is that by knowing that there indeed exists an unalterable version of truth on the blockchain, parties might lose interest in trying to trick their business partners since they know that the other party could proof them wrong anyway.

9.3 3D Printing
3D printing has been in the spotlight for a while now, and with continuous technological advances, the technology is likely to play an important role in future manufacturing processes.

Despite a general trend towards computer-based simulations through digital mock-ups, physical samples and prototypes are still relevant in product development today. Compared to other production methods (e.g. injection molding), additive manufacturing requires little investment for tooling and is therefore especially adequate for small production quantities, making 3D printing also suitable for early stage sample production. However, apart from the printing technology itself there are also other challenges that need to be resolved.

Securing intellectual property within the product development process becomes increasingly important as more and more parties become involved. The rise of R&D collaborations, a shift towards using more and more engineering service providers, as well as the trend towards simultaneous engineering requires individual companies to protect their data.

Although this use case was found in existing literature, novelty lies in its potential impact on R&D activities in particular.
9. Blockchain Applications in Research & Development

9.3.1 SAMPL

SAMPL (Secure Additive Manufacturing Platform) – a cooperation project between different organizations such as Airbus, Prostep, NXP, or the Fraunhofer Institute, as well as various universities – identified these challenges as followed (SAMPL, 2017).

Copyright – Intellectual property in the form of printable 3D-files needs to be protected. Similar to the problems the music- and movie industry faced, manufacturers also need to protect files from piracy and counterfeit products.

Identifying originals – Manufactures do not only want to prevent counterfeit parts from being produced in the first place, they also need to ensure that, if counterfeit parts do exist, the original parts can be clearly identified as such and distinguished from unauthorized copies.

Liability – In the case of warranty and product liability, manufactures need to be able to show exactly where and when a certain part was produced.

Security – It furthermore needs to be ensured that only authorized entities have access to the data. This first requires unequivocally identification of whoever wants to access the data.

Safety – It needs to be ensured that no unauthorized change to product data or features can take place. This becomes especially important when parts have safety relevance and need to hold up to high quality standards.

The SAMPL project, which is partly funded by the German government, tries to create a blockchain enhanced 3D printing platform that allows data owners to have full control over their files. Their approach sees a platform that creates a ‘chain of trust’ between the intellectual property owner and the final customer. It includes all intermediaries, the printing service provider, as well as the 3D printers themselves (‘trusted 3D printers’) which’s controls need to be certified, too. This chain of trust is complemented by a blockchain based layer that provides all license and copyright information. Within the chain of trust, every action must first be authorized on the license layer and will then be recorded on it as well. By making use of smart contracts within the license layer, product owners can address specific quantities to different service providers, knowing that certified printers will only print the exact quantity they are licensed to.

But the project does not only want to effectively track and secure data up to the point the part is printed, traceability of parts should continue once the physical part exists. By imprinting RFID-chips onto the parts, each part can be given a unique identity on the blockchain and thus be tracked throughout its entire lifecycle.

Other companies are taking similar actions, with General Electric already having filed a patent for a blockchain based distributed manufacturing platform in 2017 (US Patent & Trademark Office, 2018), and 3D printer suppliers such as HP being involved in various projects (Feldman, 2018).

Blockchain based 3D printing platforms could essentially allow data owners to share data without having to give away the actual file.

9.4 Digital Product Backbone

Another concept which could affect development processes is the idea of blockchain-based data- and configurations management, which could help manage complexity and increase traceability of product sub-systems. This concept was ideated by the author and thus very little information was to be found in existing literature. Therefore, only the basic idea will be described in the following.
9.4.1 Idea

As complexity in electric/electronic systems increases, traceability of E/E components from early systems engineering to after sales becomes increasingly difficult. Configurations are currently defined through traditionally structured part lists (bill of material). Furthermore, technical documents such as CAD files are also attached to this bill of material, thus further increasing size and complexity of the part list (Heber & Groll, 2017).

Heber & Groll (2017) therefore describe the idea of creating a blockchain based digital twin of individual products or subsystems, acting as product backbone and including all relevant information as metadata. In theory, this digital twin is able to successfully link every configuration and change a product has undergone to one another, as well as put them in the right chronological order.

If a sub-system is handed over from supplier to OEM, the OEM can mirror the sub-systems blockchain. This allows to not only receive all relevant product information in the right chronological order, the OEM is also able to link subsequent blocks to the already existing (mirrored) blockchain, ensuring configuration traceability along the product’s entire lifecycle.
10. Analysis

Addressing the topic of blockchain in manufacturing and R&D from a more general perspective, the technology will first be evaluated according to the theories presented in chapter 5.

Afterwards the three potential applications of blockchain-technologies in R&D (as described in chapter 9) will be evaluated in-depth based on interview responses and literature findings. Each use-case will then be categorized along the Adoption Matrix for Foundational Technologies (chapter 6.2).

10.1 Assessing the State of Blockchain in Manufacturing and R&D

In the following, the blockchain technology will be evaluated along the theories presented in chapter 5.

10.1.1 Technology adoption

It must be stated that the overall knowledge about blockchain-technologies and its potential applications in manufacturing and R&D was rather limited amongst interview participants. This, combined with the scarcity of already established applications in the manufacturing industry today, supports the case that overall adoption is not very advanced at this point. As Joseph M. Woodside’s 2017 study (chapter 5.2.2) already suggests, only applications in the finance industry are likely to have reached the early adopters stage at this point. It can therefore be concluded that blockchain in manufacturing and R&D is likely to still reside in the innovators stage.

10.1.2 Technology improvement

Analyzing the current literature on blockchain technology it becomes clear that for a large number of potential use-cases to be feasible, the technology needs to improve in key areas (chapter 4.4). It is those technical obstacles (especially the limited scalability and the relatively high costs), that prevent blockchain-technologies from really improving. However, if these technical challenges can be overcome, blockchain is likely to leave the infancy phase, and enter its explosion phase where performance will improve exponentially.

10.1.3 The pace of technology substitution

The technology adoption matrix developed by Adner & Kapoor (chapter 5.4) puts a focus on the respective technology’s ecosystem. It takes the new technology’s emergence challenges, as well as the old technology’s extension opportunities into account.

Ecosystem extension opportunities (old technology):

Most potential blockchain use-cases in manufacturing and R&D are in competition with traditional software solutions. Although software products themselves are constantly being improved, extension opportunities within their ecosystem have become rarer. While in the past, factors such as processing power or internet speed were limiting traditional software solutions, we seem to have reached a point where software is rarely limited by external factors.

Ecosystem emergence challenge (new technology):

External factors such as the lacking legal frameworks (as described in chapter 4.4.2) are likely to further delay blockchain adoption. It can therefore be stated that the blockchain’s ecosystem emergence challenges are relatively high.

With low extension opportunities within traditional technologies’ ecosystems, but rather high emergence challenges within the blockchain’s ecosystem, quadrant 3 (illusion of resilience) seems to be
10. Analysis

where blockchain-technologies fall into. This means that adoption is likely to stagnate until emergence challenges can be resolved. For this period market shares are unlikely to shift and will remain with traditional software solutions. However, once the blockchain’s emergence challenges can be resolved, substitution could be quite rapid.

10.1.4 Gartner hype cycle

Given that the initial hype around blockchain seems to have faded, it is likely that the Peak of Inflated Expectations has been surpassed. However, the real question is whether or not the Through of Disillusionment has been reached yet. Although no decisive answer can be given, it is likely that the blockchain-technology as a whole is either at, or close to it. It seems as if adopters throughout different industries have shifted their focus back towards specific applications where the technology can really bring an advantage.

10.2 Defensive Publishing

The following will present an in-depth analysis of the use-case Defensive Publishing as described in chapter 9.1.

10.2.1 Interview responses & interpretation

Responses varied depending on the interviewee’s individual position, as well as the orientation of his/her department. As a general trend it could be observed that more research-based departments saw generally more potential for the application. The most positive response (8 out of 10 for potential) regarding potential came from an individual working for a German research institution. His argument was that although lab books do exist, they provide little evidence in hindsight as they can be altered at will. The research institute however has great interest at being able to prove previously existing knowledge when needed.

Averaged amongst all five respondents, the applications potential was seen at a 6.8 out of 10, while likelihood was seen at 5.1 out of 10. Given that a market ready solution was available today, participants answered that it would take an average of 2.9 years before the process was fully implemented.

It must be noted that R&D is a very broad field, and not everyone is directly involved with new intellectual property that must be secured against competitors. It is thus likely that responses vary greatly depending on individual’s position within the company, and the company’s involvement in scientific research. It must further be noted that the main objective must be to file a patent, and that the blockchain application as presented should merely be regarded as an additional tool in getting there.

10.2.2 Adoption matrix

Novelty: Since the only way for a company to protect its intellectual property today is to file a patent as soon as possible, being able to proof one’s research progress beyond any doubt constitutes a high degree of novelty.

Complexity: Compared to other blockchain solutions, technical complexity ranks rather low. However, while the technical complexity itself is rather low, establishing this use-case as an accepted standard could still present challenges as both patent offices and courts need to agree. This assumption is also supported by the questionnaire, where despite market ready solutions the implementation time-frame was estimated to be almost three years.

With a high degree in novelty, but a low to medium degree in complexity, Defensive Publishing can be assigned to the second quadrant (Localization).
10.3 Securing Specifications & Change Requests on the Blockchain

The following will provide an in-depth analysis of the idea of storing specifications and change requests on a blockchain (as described in chapter 9.2).

10.3.1 Interview responses & interpretation

Respondents evaluated the concept with an average potential of 7.1 out of 10, and a likelihood of 6.4 out of 10. They further stated that if the decision to adopt blockchain based solution was made today, and given that a market ready solution is available, it would take the companies an average of 2.8 years before the process was fully implemented.

Interview respondents seem to have a strong interest in better and more transparent solutions for managing change requests and specifications. This implies that many companies in fact have problems in this area. It must be noted, however, that traditional software solutions for managing change requests and specifications do exists, and that most companies could improve transparency and traceability by improving or adopting traditional software solutions.

10.3.2 Adoption matrix

**Novelty:** Given that traditional document management systems have been in use for a while, it can be concluded that the degree of novelty is fairly low.

**Complexity:** While the technical complexity itself is rather low, establishing this use-case as an accepted standard could present challenges. Although implementation on an organizational level would not be too hard, the difficulty lies in turning it into a standard which will be accepted by various development partners.

With a relatively low degree in novelty, but a medium to high degree in complexity, Defensive Publishing can be assigned to the third quadrant (Substitution).

10.4 3D Printing

An in-depth analysis of the idea of blockchain-based 3D-printing networks (as described in 9.3) will be presented in the following.

10.4.1 Interview responses & interpretation

Blockchain enabled 3D-printing was accredited with an average potential of 6.2 out of 10 amongst all seven participants. Likelihood was seen slightly lower with an average score of 5.6 out of 10. The possible Implementation time-frame was estimated to be around 3.4 years.

At the time of this thesis, research on blockchain-based Product Data Management seems to be in its infancy. Before a more conclusive evaluation on the subject can be conducted, existing ideas must be turned into functioning prototypes and compared with current solutions. It is, however, a concept that should be closely monitored over the next months and years.

10.4.2 Adoption matrix

**Novelty:** Since data protection in 3D-printing through a blockchain-based solution is a completely new concept, novelty ranks high for this use-case. This assumption is supported by the fact that none of the interview participants have heard about this approach before.

**Complexity:** Realizing a blockchain-supported 3D-printing network requires not only a working technical solution, printing contractors also need to become certified. The fact that so far only prototypes and concepts exist speaks for a high degree of complexity.
With a high level of complexity and novelty, blockchain in 3D-printing must be placed in the fourth quadrant (Transformation).
11. Conclusion

Blockchain – the technology behind virtual currencies such as Bitcoin – is being promoted by many as one of the most promising emerging technologies. Similar to the internet in its early days, blockchain (often referred to as Distributed Ledger Technology) must be seen as a foundational technology, enabling a great variety of potential applications. In theory, most software applications today could somehow be realized through- or complemented by blockchain. However, since the blockchains’ security attributes do not always outweigh the speed- and cost advantages of conventional software solutions, not every application that can be realized through blockchain should be.

At its core the blockchain is a distributed, immutable data base, able to pinpoint exactly when and by whom a given transaction has been made. After a certain amount of individual transactions have been conducted within the network, these transactions are being summarized in a block and subsequently added to the blockchain. With the help of cryptographic hash functions, every block is linked to both its predeceasing- and succeeding block. This essentially results in a chain-like connection where all blocks are securely connected to one another. The fact that whenever a new block is to be added to the chain a majority of the network needs to first agree on the current state of the entire blockchain – consensus mechanism – makes the information stored on the blockchain virtually tamper-proof and creates an irreversible record of transactions.

However, this consensus mechanism is also what greatly limits transaction speed and subsequently scalability of blockchain applications. Although transaction speeds and other limiting factors are constantly being improved, the blockchain should not be seen as the solution to all of world’s problems but much rather as a technology that can bring great value in very specific environments and applications.

Aspects that do favor the use of blockchain include multiple parties sharing and updating shared data, the need to be able to trust the records, the existence of intermediaries that add costs, as well as missing trust between the parties involved.

Some of the blockchain’s key advantages include disintermediation, improved traceability of products, increased transparency of transaction histories, as well as enhanced security of records regarding fraud and unauthorized activities.

In respect to objective 1 – identify and describe the most relevant potential blockchain applications within manufacturing industries – it can be stated that the manufacturing industry is lacking behind the financial industry in terms of blockchain adoption. Nonetheless, the thesis is able to identify three main categories where blockchain technologies most probably will affect manufacturing companies.

Within the supply chain and logistics sectors, manufacturing companies will benefit from increased traceability and visibility of supply chains. Blockchain could, for example, help to ensure that all parties within the supply chain access very same documents and information, thus reducing the risk communication or data errors and help reduce administrative costs. Knowing exactly how parts and finished goods are being passed through the chain of subcontractors can also help to decrease losses from counterfeit products, as well as allow OEM’s to exactly pinpoint where specific parts came from in case of malfunctions. This can further help companies to proof that materials were sourced in alignment with corporate social responsibility standards.

The Internet of Things (IoT) – a future key driver of industrial growth in itself – is also said to benefit from blockchain technologies. Security of IoT systems (or Industrial Internet of Things as referred to in a manufacturing context) will be enhanced as the blockchain can enable network systems without the need of a central cloud server. This central cloud server architecture is what makes IoT systems vulnerable to hacking attacks as every device within the network can grant hackers access to the entire
system (single point of failure). Furthermore, the blockchain can help to identify and authenticate individual IoT devices, a process that currently requires third party certification which again is adding costs and limits scalability of networks. Projects such as the Trusted IoT Alliance, which amongst other consists of Bosch and Cisco Systems, are already working on blockchain based IoT ecosystems and have already launched test networks.

The third and last category where blockchain most probably will transform manufacturing is distributed manufacturing. Distributed manufacturing, mainly in the form of 3D printing, will allow companies to increase production flexibility, shorten shipping routes, and significantly reduce the need for in-storage spare parts. Blockchain solutions will thereby help to secure intellectual property (e.g. construction files) whenever printable files are sent to contractors or other third parties. By equipping parts with RFID-chips or other identification measures it will furthermore be possible to trace products from the very moment they were created. Projects such as SAMPL (Secure Additive Manufacturing Platform), a cooperation between companies such as Airbus, Prostep, and the Fraunhofer Institute, are already trying to establish blockchain-based 3D-printing platforms that will help increase security in additive manufacturing. The project’s goals are to protect files from piracy, help identify originals, ensure traceability of printed parts, secure data from unauthorized access, as well as ensure integrity of individual files.

Regarding main objective 2 – examine if and how the technology could affect R&D processes within manufacturing companies – it must be concluded that, at least at this point of time, blockchain-technologies are generally better suited for other environments such as logistics, financial, or the public sector. Many of those blockchain favoring caricaturists described above (multiple parties sharing and updating shared data, the need to be able to trust the records, existing intermediaries that add costs, and especially missing trust between the parties involved) only partly apply to R&D environments, making traditional software solutions often favorable. However, blockchain, as explained earlier, enables a variety of different applications, some of which can also bring value to R&D departments.

Blockchain-based 3D printing solutions as described above can also become relevant within product development. The small production quantities of prototypes or early samples make 3D printing a good alternative to investment heavy production methods such as injection molding, especially at the early stages of product development. The previously mentioned SAMPL project, as well as similar initiatives should therefore be monitored closely.

Similar to how the blockchain could protect files within 3D printing processes, it might eventually be possible for the technology to help secure files within virtual simulation- and test environments. Simulations might someday be run in a virtual black-box, providing companies the simulation results needed without giving access to the actual construction files. However, there are no projects or initiatives on the topic yet, making it unlike to appear anytime soon.

An application that is currently much more feasible from a technical standpoint is the storing of hash values on a blockchain. Amongst others, Bernstein Technologies have developed a service that allows companies to turn any file of unlimited size into a fixed numeric code (hash value) which is then stored on the blockchain. By its nature, a hash value does not reveal any information about the underlying document. However, every time an identical file is inserted into the same hash-algorithm, it will result in the very same hash value. With every block on the blockchain containing a timestamp, and combined with the irreversible nature of the blockchain, this concept referred to as defensive publishing lets companies effectively proof that they were in possession of a certain document at a given point in the past without having to prematurely reveal its content. A prime example where this concept could be used is laboratory notebooks. Research institutions have a great interest in being able to proof to legal institutions or competitors that the content of their laboratory notebooks has not been altered afterwards.
Similar to the concept of defensive publishing, virtually any document can be turned into a hash value and stored on the blockchain. This could proof valuable wherever there is an interest in being able to later proof that the document in question has not been altered. Product specifications and change requests are another example where R&D departments might have an interest in having an immutable ‘single version of truth’ of the document stored on the blockchain.

In both cases the blockchain essentially takes on the role of a notary. However, blockchain solutions can provide the service for a fraction of the cost and with far better automatability and scalability.

An at the moment rather vague potential use-case is the blockchain’s possible involvement in creating digital product backbones in form of a products digital twin. Although an idea has been published that describes a scenario where a majority of documents related to a given product are stored (or at least a referenced to) on the blockchain, it will most likely take years before the first prototypes are operational. Nonetheless, the idea holds great potential and should therefore be monitored over the coming years.

In conclusion it can be stated that the blockchain is a technology that will affect most if not all areas of business in some way or another. However, since the blockchain’s greatest potential lies in its ability to disintermediate and optimize very specific processes, companies should first evaluate exactly where and how they could benefit from it and whether blockchain-based solutions could provide an advantage compared to traditional ones. Rather than quick and disruptive, overall adoption to the technology is likely to be more gradual, starting with the most rudimentary applications and slowly gaining momentum as the technology itself, individual products, as well as the legislation surrounding it improve.
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