University of Economics, Prague

Faculty of Informatics and Statistics

Potential of using the Blockchain technology for project management

DIPLOMA THESIS

Study programme: Applied Informatics

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Thesis supervisor: Ing. Jan Kučera, Ph.D.

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Declaration

I hereby declare that I am the sole author of the thesis entitled “Potential of using the Blockchain technology for project management”. I duly marked out all quotations. The used literature and sources are stated in the attached list of references.

In Prague on 29 April, 2019 .....

Yekaterina Matosyan

Acknowledgment

It is a great pleasure for me to acknowledge the assistance and contributions of many individuals in making this thesis a success.

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Abstrakt

Předmětem dané diplomové práce je technologie Blockchain, její současné možnosti a budoucí potenciál. Cílem této diplomové práce je analýza potenciálu využití technologie Blockchain v oblasti projektového řízení. Pro dosažení primárního cíle této diplomové práce autor provedl komplexní empirickou práci skládající se ze třech etap. V první etapě se autor zaměřil na sběr a analýzu stávajících služeb založených na technologii Blockchain a aktuálních problémů vznikajících při řízení projektů. V rámci druhé etapy autor namapoval vztah mezi kategoriemi služeb založených na technologii Blockchain a identifikovanými problémy projektového řízení na základě analogie za účelem identifikace potenciálních případů užití technologie Blockchain v projektovém řízení. Výsledkem druhé etapy empirické práce je 8 identifikovaných potenciálních případů použití technologie Blockchain v oblasti projektového řízení. V třetí etapě empirického výzkumu se autor věnoval realizaci expertního vyhodnocení 8 navržených případů užití dle definované sady hodnotících kritérií. Na základě získaných výsledků expertního hodnocení autor zjistil, že řešení navržené pro Řízení projektových nákladů je uznáno za nejvíce životaschopný a technicky proveditelný případ užití technologie Blockchain pro oblast projektového řízení.

Hlavním výstupem této diplomové práce je koncepčně navržené řešení pro Řízení projektových nákladů. Navržené řešení je prezentováno pomocí UML diagramů.

Klíčová slova

Technologie Blockchain, blokchain-založené služby, případy užití Blockchainu, inovace, projektové řízení.

JEL klasifikace

O31, O33, L86

Abstract

The subject of this diploma thesis is Blockchain technology, its current possibilities and future potential. The main aim of this diploma thesis is to analyse the potential of using Blockchain technology in the project management domain. In order to achieve the primary thesis objective, the author of the thesis performed the comprehensive empirical work consisting of three stages. In the first stage the thesis author aimed to collect and analyse of existing blockchain-based services and actual problems arising during project management. In the second stage of the empirical research the author of the thesis focused on mapping based on the analogy between the defined blockchain-based services categories and identified project management problems in order to identify the potential of Blockchain use cases suitable for the project management area. The outcome of the second stage of the empirical work are 8 identified potential Blockchain use cases suggested for the project management area. In the third stage of the empirical work the author has carried out the evaluation procedure of the 8 identified use cases under a specified set of assessment criteria with the help of project management experts. Based on the collected set of expert assessment results the author acknowledged that the solution suggested for Project Cost Management is the most business viable and technically feasible Blockchain use case for the project management domain.

The main thesis outcome of this diploma thesis is a conceptually designed solution for the Project Cost Management. The designed solution is presented with the aid of UML diagrams.

Keywords

Blockchain technology, blockchain-based services, Blockchain use cases, innovation, project management.

JEL Classification

O31, O33, L86

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Introduction

Information technology is constantly evolving and changing the world for the better. It facilitates not only human daily routine activities, but also helps optimize business processes. Nowadays information technology plays the same role for many companies. Such companies could not have succeeded without the employment of innovations. They are essential for survival in a modern highly competitive market place. Therefore, each company should continuously follow and evaluate new information technology trends to improve not only their business processes but also their provided services. However, the half-life of innovation gets shorter and shorter. "*Technology-based innovation is arriving faster than most organisations can keep up with. Before one innovation is implemented, two others arrive*", says Daryl Plummer, Gartner's vice president at the Symposium/ITxpo 2018 in Orlando (Plummer, 2017a). The companies that really want to use new technology effectively need to be faster. Because while the technology isn't fully used by others, the more competitive advantage is achieved. Furthermore, "*the digital business efforts move into higher gear*" (Plummer, 2017a). The relationship between strategy and innovation is vital. There is no point in implementing new technology when it does not bring back value to the company. Proper and appropriate use of innovation in a complementary way is when used technologies support one another and operate in a harmony with the firm strategy. CIOs and IT leaders need to develop a pace when elaborating their innovation strategy that can be sustained no matter what the future brings, otherwise they risk to lose position on the market due to uncompetitiveness (Plummer, 2017b).

On the 15th October, 2018 the leading research and advisory company Gartner, Inc. presented TOP 10 Strategic Technology Trends for 2019. For the last two years Gartner grouped the trends into three themes called "Intelligent Digital Mesh". This year a presentation was carried out in the same way as previously based on the vision of the future digital ecosystem. The Gartner's list of the trends for the year 2019 is following: Autonomous things, Augmented analytics, AI-driven development, Digital Twins, Empowered edge, Immersive experience, Smart space, Digital ethics and privacy, Quantum computing and Blockchain (Gartner, Inc., 2018b). The current trends have sufficient potential to disrupt all existing rules and practices, to drive a continuous innovation process for the next five years and as a result to change the business models (Cearley, 2018). Some of today's trendy technologies are already in use, for example: robots and drones for shipping, digital twins are visible in medicine, messenger bots and voice-activated chatbots as part of immersive technologies. But all existing possibilities are a little piece of what we can expect in the future. According to Gartner's forecast the interconnection of all mentioned technologies will bring us much more benefits and opportunities, totally change the business and affect our everyday life (Gartner, Inc., 2018b).

Unlike the other strategic technology trends listed above, the future of the Blockchain technology seems to be more undefined and unclear. Blockchain is an open distributed ledger technology underpinning cryptocurrency which uses software algorithms to record transactions or any digital interaction with immutability, reliability, security, cost-efficiency

and elimination of intermediaries (Deloitte, 2016). The Blockchain technology is different from existing traditional solutions. The difference can be explained by its 5 fundamental underlying principles: distributed database, per-to-peer transmission, transparency with pseudonymity, irreversibility of records and computational logic (Iansiti and Lakhani, 2017, p. 119). An overwhelming majority of today's Blockchain projects are just blockchain-inspired. Since they don't strive to utilize all 5 key principles of the technology at once to implement the "pure" Blockchain network including all given benefits and limitations as well. "*Current Blockchain technologies and concepts are immature, poorly understood and unproven in mission-critical, at-scale business operations*", said Mr. Cearley, as he presented on the top strategic predictions for 2019 and beyond by Gartner (Cearley, 2018). The hype around cryptocurrencies such as Bitcoin and Ethereum made the technology to seem as a good idea for start-up project. Since 2008 projects have been developing with a vision of prosperity by utilising this revolutionary technology. But only a few of them fulfil Blockchain's potential and offers new digital age solutions. According to statistics provided in May 2018 by China Academy of Information and Communications Technology (a scientific research institute under the Ministry of Industry and Information Technology of China):

— the average life of the Blockchain project is less than 2 years;
— more than 80 thousand projects have been launched worldwide since the invention of Blockchain technology,
— 92% of these projects have already failed and just 8% are still alive (Maloney, 2018).

Asian countries such as China, Japan and Singapore are presently leading approximately a half of 1 121 active Blockchain projects all over the world (ChainDD, 2018). Nevertheless, Blockchain technology has been already adopted by the financial sector, supply chain management, manufacture, medicine and other. CIO's should continue to invest resources into the evaluation of the Blockchain technology possibilities and their future adoption. "*Blockchain will create $3.1 trillion in business value by 2030*" (Gartner, Inc., 2018c).

Based on the lack of information it can be assumed that the potential of using the Blockchain technology in the field of project management is not fully recognized up until now. Project management is an important part of the today's business world, in view of the fact, that it has a significant impact on the firm's productivity, especially in project oriented organizations. What if the new revolutionary technology can offer several advantages over existing traditional solutions and somehow change the project management paradigm for the better? To answer this question this diploma thesis aims to explore and analyse the potential of using Blockchain technology in project management.

Goals, metrics, and indicators

The main aim of this diploma thesis is to analyse the potential of using Blockchain technology in project management. In order to achieve this thesis primary objective is broken down into several measurable secondary objectives. Evaluation methods and indicators were suggested for each secondary objective to monitor and to measure the work

progress and to evaluate the diploma thesis outcomes. All thesis secondary objectives together with indicators and evaluation methods are described in the Table 1 located below.

Table 1: List of the thesis sub-objectives including metrics and indicators (Author)

№	Secondary objectives	Evaluation methods	Indicators
1.	*Execution of the research for existing blockchain-based services*	*Are the research results interpreted sufficiently and in a comprehensible format? Is the way of sorting and categorization evident?*	*Categorized and sorted list of the existing blockchain-based services together with category, accurate description of the functionality, area where it is in use; the results must be summarized in a table for clarity.*
2.	*Realization of the research for actual project management problems*	*Are the research results interpreted sufficiently and in a comprehensible format? Are the used sources valuable and reliable?*	*Traceability matrix identified project management problems covered by used information sources.*
3.	*Identification of potential Blockchain use cases for the project management area*	*Why such categories of blockchain-based services are considered as suitable for resolving project management problems? Are identified use cases explained sufficiently and understandably?*	*Clear explanation of the identified Blockchain use cases for the project management purposes including advantages of the applying*
4.	*Evaluation of the business viability and the technical feasibility of the identified use cases*	*Does the evaluation criteria characterize the business viability and the technical feasibility of the identified use cases?*	*Clearly evaluated use cases by the defined set of assessment criteria*
5.	*Design of the most relevant Blockchain use case for project management purpose*	*Does the model have added value for the project management domain?*	*Designed concept models must be based on assessment's results and be developed in accordance with project management requirements and Blockchain technology limitations as well*

Thesis structure

This diploma thesis is composed of ten main chapters, which are broken down by context into specific parts of the thesis work. The thesis structure is as follows:

- Introductory part – 1. Chapter,
- Methodological part – 2. chapter,
- Theoretical part – 3. chapter,
- Practical part – 4.-8. chapters,
- Concluding part – 9.-10. chapters.

The introductory part contains the second chapter that presents comprehensive *Literature review*. In this chapter, several approaches are applied in order to verify relevance of the topic and to define key information sources for the theoretical basis of the thesis work.

The methodological part of the thesis consists of third chapter devoted to the *Approach and methods*. The subject of this chapter is to define the work methodology and to determine the procedures and methods used during the writing of this thesis.

In the theoretical part, the fourth chapter about *Blockchain technology* focuses on the explanation of how the Blockchain technology works, describing the advantages and disadvantages and the current state of the technology at the end of year 2018.

The practical part is dedicated to the design science research and consists of the sixth, seventh and eighth thesis chapters. The practical part starts with the fifth chapter *Blockchain-based services*. This chapter introduces the actual possibilities of the Blockchain technology by presenting a list of existing blockchain-based services which are additionally sorted and grouped into categories for further analysis in the following chapter. The next chapter *Blockchain for project management: use cases* describes the mapping between particular blockchain-based services categories and project management problems with the purpose of the identification of potential Blockchain use cases in the domain of project management. The identified Blockchain use cases are presented and described in the sixth thesis chapter as well. The following chapter *Evaluation of use cases* describes the entire evaluation process especially selecting the focus group, the suggestion of evaluation criteria, the analysis of results and other issues related to the design research workflow. The last practical chapter is the eighth which attempts to design the *Blockchain-based project management software tool*.

The concluding part of the thesis describes the findings and outcomes in the chapter *Discussion*. The last tenth thesis chapter *Conclusion* delivers the summarization of the complete thesis work, provides answers to the thesis problems in order to achieve the main thesis aim and gives a direction for the future research.

Assumptions and limitations

This thesis is intended for all people interested in Blockchain technology and its prospects and challenges. The thesis topic requires information technology background and familiarity with the project management discipline from its readers.

The primary focus of this diploma thesis is the exploration of the Blockchain technology in the field of project management and its potential in other areas. Such areas are only briegly indicated in this thesis.

The thesis work deals only with the technological aspects of the identified Blockchain use cases in project management. Other economical, regulatory, legal, social, ethical, financial and many other aspects are out of scope of this work, nevertheless they can be shortly indicated within the limitations of the proposed solutions.

This thesis contains an Evaluation chapter. This chapter is about the qualitative evaluation of selected blockchain-based use cases by a group of experts from the project management field. The evaluation is based on experts' personal opinions influenced by knowledge, experience and bias. The evaluation results may differ from the results gained from the other focus group.

Several blockchain-powered use cases including their advantages and limitations are presented in this thesis work. It is necessary to take into account that this work reflects the state of the Blockchain technology as is on the publication date of this work.

Outcomes and expected benefits

The main thesis outcome is the concept model of the project management solution designed on the basis of Blockchain network. The other outcomes are:

- a set of potential use cases of Blockchain technology for project management purposes;

- evaluation of the business viability and the technical feasibility of the identified use cases.

One of the thesis diploma benefits is in gaining an overview about the existing blockchain-based services. Based on the analysis and expert's evaluation of the most suitable use cases the thesis work proposes a new insight into how things can be done differently within the Blockchain advantages in the area of project management.

Due to the fact that the thesis work is concerned with the exploration of existing and new blockchain-based services it may be useful for organizations which are already employing the Blockchain technology or considering an investment into new innovative blockchain-powered solutions.

Terminology

Several fundamental terms were identified during the conducting of the literature review and key information study sources. The definition of these terms is essential for the understanding of the topic discussed in this thesis work.

Blockchain is a technology based on the virtual digitized decentralized network with "blocks" of information (Murgai, 2018, p. 59). Blockchain constitutes a distributed ledger that records and shares transactions in blocks across a network of participant nodes (Saleh, 2018). Each cryptographically signed, irrevocable transactional record contains a time stamp and reference links to previous transactions. With this information, anyone with

access rights can trace back a transactional event, at any point in its history, belonging to any participant. (Gartner, Inc., 2018a).

Blockchain-based service is a service that is being delivered on the basis of the Blockchain technology using its technological principles and features.

The *Bitcoin network* is an innovative payment network with a digital form of money. Bitcoin is public, open-source, peer-to-peer network that carries out the managing of transactions and the issuing of bitcoins collectively by the network in order to operate without any central authority (Bitcoin.org, 2019a).

Cryptocurrency is a decentralized virtual currency which is electronically transmitted between parties through the Blockchain network without a central repository, single administrator or a bank (Shasky Calvery, 2013). The most famous cryptocurrency is Bitcoin.

Hash is a special class of the math functions applicable for cryptography (Singhal et al., 2018, p.56). Cryptographic hash is an asymmetric function that converts an input data (letters and numbers) into an encrypted output of a relative short fixed-length (Singhal et al., 2018, p.56). The output value returned by the hash function is named as fingerprint or simply hash.

Mining (in context of Blockchain) is an intentionally resource-intensive computational process, consuming large amounts of processing power and memory (Yaga, et al., 2018, p. 23). Mining is defined and regulated by Blockchain's consensus algorithm for the purpose of data integrity protection and security of the system. In the case of Bitcoin, mining operates under Proof of Work (PoW) consensus protocol lied in recording verified transactions to the Blockchain's distributed public ledger by inclusion them into validated blocks.

Mining node or miner (in context of Blockchain) *"is a computer running Blockchain software"* (Yaga, et al., 2018, p. 23), that is rewarded with a cryptocurrency for performing required work needed for maintaining the Blockchain.

Project management is the application of knowledge, skills, tools, and techniques to project activities to meet the project requirements (PMI, 2018b).

Project management tool is a software application that enables to plan tasks and activities, develop estimates, organize and control the work in order to meet the project objectives. Depending on the application's complexity, the tool offers various possibilities to PM's, stakeholders and users such as:

- project planning,
- scheduling,
- track project progress,
- resource allocation,
- manage budgeting,
- control costs,
- quality management

- change management
- risk management
- reporting
- collaboration
- communication
- document sharing
- etc.

Smart contract it's a digital form of contract implemented as a software program or protocol that includes set of predefined conditions in order to verify or enforce the performance of promises between parties (Szabo, 1996).

1 Literature review

The literature review chapter is focused on the verification of the relevance of the analysed topic and on the identification of the key literature sources, which will be used as a theoretical basis for the diploma. The literature review was executed in three stages: relevance of the theme, literature search analysis, citation analysis. The chapter was divided into three parts in accordance with mentioned execution stages. The key literature sources are listed at the end of this chapter.

1.1 Relevance of the theme

Firstly, the verification of the relevancy of the diploma thesis theme was accomplished based on the analysis of popularity of the Blockchain technology topic with the aid of frequency of search queries. A special tool Google Trends was used for these purposes. It allows to demonstrate graphical statistics of how often the particular word or phrase has been queried via Google in a specified period of time and across various countries. Today Google search is the most well-known and applied search engine throughout the world, insights gained from Google Trend tool have a verifiable value and may be considered as relevant and appropriate basis for drawing conclusions. The Figure 1 below represents a trend curve of how often people around the world have been searched for information about Blockchain technology over the past 10 years. Alongside it reflects the historical evolution of Blockchain.

Figure 1: Evolution of the search for “Blockchain technology” between 2008 and 2018 (Google Inc, 2018)

The 2008 is the year when Blockchain technology was presented to serve as the public transaction ledger of the cryptocurrency Bitcoin (Nakamoto, 2008). Until 2014 technology was used entirely to support cryptocurrency payments. After introduction and release of the new blockchain-based platform Ethereum attention shifted from Bitcoin to the technology itself. In 2015 Ethereum came with a new vision of usage of the distributed transaction ledger in order to lay the fundament for other blockchain-powered solutions by enabling the Smart Contracts and Distributed Applications. It is interesting, that the idea of Smart Contracts was firstly introduced in an article of a famous computer scientist and

cryptographer Nick Szabo in early 1996 (Gord, 2016). It took more than 20 years to transform the idea of Smart Contracts into the real working solution.

Since 2016, various blockchain-based use cases had been identified across different areas, the growth of the popularity can be seen from the trend curve above. However, Blockchain technology was still closely linked and influenced by the popularity of the cryptocurrency speculation and mining. Hype in the media around Bitcoin affected the Blockchain projects that have come into existence over the past 5 years. At the end of the 2017 Blockchain's association with Bitcoin reached the tipping point as shown by Google trend curve above. This can be interpreted as the moment when the technology began to separate from Bitcoin's fame in order to discover the potential not only in the financial area.

A lot of various blockchain-based platforms, applications and services have appeared since Ethereum launched, but only solutions with a proven potential had survived up till now. Corporations and start-ups continue looking for new opportunities of employing the Blockchain technology in various areas. Several publications about Blockchain's utilization in the financial sector, capital markets, healthcare, oil & gas trading and other can be found on the internet. For example, organizations such as McKinsey, Deloitte, IBM are regularly publishing articles, news, interviews, conversations, stories, opinions, concept solutions devoted to the Blockchain technology. The first publications about the launching of the Blockchain technology for project management appeared in the mid 2017 (Sputnik, 2017). These publications only shortly indicate the advantages of applying the technology in this domain, nevertheless the real use cases have not been well described yet in available literature. The search via Google Trends tool regarding the use of Blockchain technology in project management displays no results as of yet.

1.1.1 Research of academic works

Research of academic works was chosen as a second approach to verifying the theme's relevance and examine how the Blockchain theme is academically covered. The research was territorially limited due to the impossibility of performing an analysis of global sample. Theses.cz database was used for research execution, which enabled the access to almost all academic works successfully defended in the Czech Republic.

Firstly, the research was executed by searching the key word "Blockchain" within the Thesis.cz database. During conducting the research, the following facts were noticed:

- The investigation displayed 231 non-duplicate academic works in total;
- 60% of works found are related to the Blockchain technology;
- The remaining part of the result is 95 academic works, which are out of scope of this research. These works are devoted to the other subject matter and contain just passing reference to Blockchain technology.

In the next step the classification of the relevant results was done. All 136 academic works related to the Blockchain topic were categorized into five groups by determining their main focus. Another one classification of the research results was made by the type of academic

works. For reasons of clarity, the obtained results were additionally sorted in descending order by the year of defence and summed up in the table.

As Table 2 shows cryptocurrencies are the most popular specialization of the Blockchain related academic works in the Czech Republic. The academic works from this category are devoted to Bitcoin, speculation and mining of cryptocurrencies, dark net and the establishment of the mining company from the business point of view.

Table 2: The results of the academic works research (Data obtained from Theses.cz and analysed by the author)

Type of academic work	Year	Technology	Crypto currencies	Financial sector	Solutions for enterprises	Other use cases
Bachelor thesis	*2018*		*18*	*1*		*1*
	2017	*2*	*10*	*4*		*5*
	2016		*16*			
	2015		*16*			
	2014		*6*			
	2013		*1*			
Diploma thesis	*2018*	*1*	*9*	*2*	*1*	*3*
	2017	*2*	*10*	*6*	*1*	*1*
	2016		*2*	*1*		*2*
	2015		*8*	*1*		
	2014		*3*			
Dissertation thesis	*2018*		*1*	*1*		
	2017					*1*
Total		***5***	***100***	***16***	***2***	***13***
		136				
Percentage		4%	74%	12%	1%	10%

The works about Blockchain for financial sector discuss the digitalization of banking and the usage of the cryptocurrencies in the state financial institutions. The Blockchain technology itself and Blockchain as solution for enterprises are less popular themes.

The category “Other use cases” includes the works which are about the application of the Blockchain technology for various areas, such as the following:

- supply chain,
- insurance,
- e-commerce and retail,

- crowdfunding and crowd sale,
- real-estate,
- insurance and micro insurance,
- procurement automation,
- recruitment platform,
- freelancing,
- settlement of disputes online,
- electronic and online election,
- remittances for developing countries.

Some of the discovered academic works from the last category are included to the list of the key literature of this diploma thesis, since they represent Blockchain technology use cases which may be applicable for the project management domain.

Based on the research described above it can be concluded that the potential of using Blockchain for non-financial purposes is not fully recognized on an academic level in the Czech Republic. The works dedicated to the Blockchain technology in the non-financial area are still up to date. This diploma thesis can contribute to discovering a new specific area where the Blockchain technology can be applied and developed.

1.2 Literature search analysis

A core prerequisite for a successful literature review is the identification of keywords which help with the selection of relevant literature. This diploma thesis studies two completely different themes: Blockchain and Project management. This is way there was a need to define the keywords in accordance with the connection of these themes in order to better specify the literature required. The used key words are presented in the Figure 2.

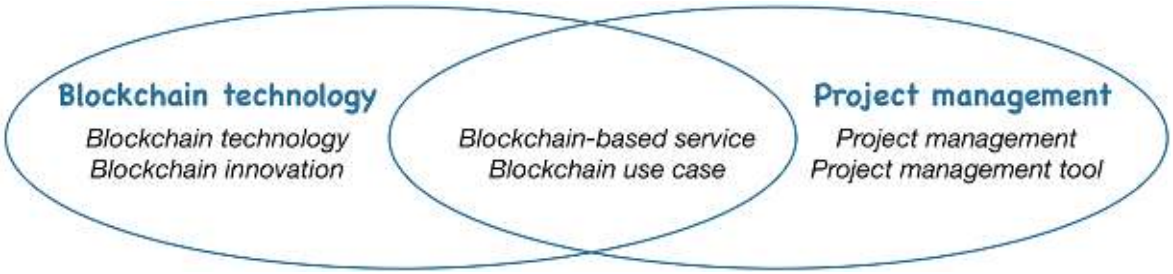

Figure 2: Key words for the search analysis (Author)

The literature search analysis was executed with the aid of Boolean operators for formulating precise search queries. The Google Scholar, ProQuest, EBSCO, NTK databases were used as a source of information for the search analysis. The search was carried out for English and full text online sources only, the results are presented in

Table 3 below. As it can be seen from the results of the search analysis there is a wide variety of literature focusing on Blockchain or Project management. Literature, which deals in some way with subjects related to both mentioned themes, is less knowledgeable.

Table 3: Literature search results (Author)

Information sources	Blockchain technology	Blockchain innovation	Blockchain-based service	Blockchain use case	PM	PM tool
Google Scholar	*14 000*	*370*	*109*	*127*	*1 810 000*	*9 860*
ProQuest	*51 941*	*1 072*	*128*	*113*	*75 624*	*726*
EBSCO	*2 191*	*835*	*240*	*111*	*31 062*	*2 344*
NTK (Techlib.cz)	*123 147*	*1 424*	*388*	*582*	*866 615*	*11 882*

However, the performed analysis itself does not indicate anything about the relevance and quality of the sources found. Therefore, as the next step of the literature review is the citation analysis which is conducted and described in the next subchapter.

1.3 Citation analysis

In this diploma thesis the citation analysis works as an instrument by which the retrieved information sources are examined for relevance, reliability and quality. The special tools were used for performing the citation analysis: Google Scholar, Scopus and Web of Science. These tools enable to sort the search results by a number of citations which can be applied as measure of relative importance or impact of the book, article or author. The Table 4 below illustrates key books and authors that have been identified through citation analysis as the most relevant and applicable for this diploma thesis. The number of citations says that publications have been cited several times by other authors. It was used as an indicator of the reliability and quality of the source.

The table below shows that the Google Scholar tool was more efficient than the other tools and provided the most telling results. During the performing of the analysis one interesting fact was detected. The citation registers such as Scopus and Web of Science index mostly scientific articles, publications and book reviews, but the books themselves are oftentimes missing there. Therefore, the performed citation analysis relies only on the results obtained from the Google Scholar.

The other relevant sources were discovered and based on the author's opinion were also included to the list of key literature of this diploma thesis. These sources have no indexation in all used citation registers. That is the reason why they are not included in the table above together with books.

Table 4: Citation analysis results (Author)

	Author	Google Scholar	Scopus	Web of Science
Project management	*Kerzner H., 2017*	*7 844*	-	-
	Schwable K., 2015	*292*	-	-
	Kerzner H., Belack.C, 2010	*32*	*8*	-
Blockchain technology	*Antonopoulos, A. M., 2014*	*668*	-	-
	Drescher,D., 2017	*100*	*13*	*1*
	Singhal, B., Dhameja, G., Panda, P.S., 2018	*2*	-	-
	Yaga, D., Mell, P., Roby, N. and Scarfone, K., 2018	*23*	-	-

Below there is a list of the key literature, which is divided into three categories with regard to the subject matter.

The key literature:

- Project management
  - Book: *A guide to the project management body of knowledge, PMBOK guide*. (PMI, 2017);
  - Book: *Project management: a systems approach to planning, scheduling, and controlling* (Kerzner, 2017);
  - Book: *Information technology project management* (Schwalbe, 2016);
  - Book: *Managing complex projects* (Kerzner and Belack, 2010);

- Blockchain technology
  - Book: *Mastering Bitcoin: unlocking digital cryptocurrencies* (Antonopoulos, A. M., 2014);
  - Book: *Blockchain Basics: A Non-Technical Introduction in 25 Steps* (Drescher, D., 2017);
  - Book: *Beginning Blockchain: A Beginner's Guide to Building Blockchain solutions* (Singhal, B., Dhameja, G., Panda, P.S., 2018);
  - National Institute of Standards and Technology Internal Report: *NISTIR 8202 Blockchain Technology Overview* (Yaga, D., Mell, P., Roby, N. and Scarfone, K., 2018);

- Blockchain based services
  - Diploma thesis: *Leveraging Blockchain in Enterprises* (Jelačič, 2018);

— Diploma thesis: The Blockchain-enabled Supply Chain and Its Impact on Sourcing and Transactional Functions of the Procurement Process (Sulíková, 2018);
— Diploma thesis: *The Digital Economy, Industry 4.0 and digital payment systems: impacts on international organizations* (Mojžíš, 2018);
— Bachelor thesis: *Crowdsale ako druh crowdfundingu k financovaniu inovatívnych projektov (Crowd sale as a type of crowdfunding to fund innovative projects)* (Kopalko, 2018);

The books about Blockchain technology were used for the theoretical basis of the thesis work to cover all technical aspects of the Blockchain as well as its limitations and benefits. The theses from the third category were used as an inspiration for alternative use cases of the Blockchain technology which can be applicable for the project management domain. The books devoted to project management were used as a helpful source of essential information and best practices for designing a concept model of the blockchain-based solution for project management purpose.

2 Approach and methods

Correctly defined methodology makes the work more meaningful, useful and valuable. Hence it is necessary to define the work methodology as it also describes the whole process including the procedures and approaches used. This chapter concerns the methodology and serves as the framework for this diploma, as well as to structure the empirical work performed within this thesis.

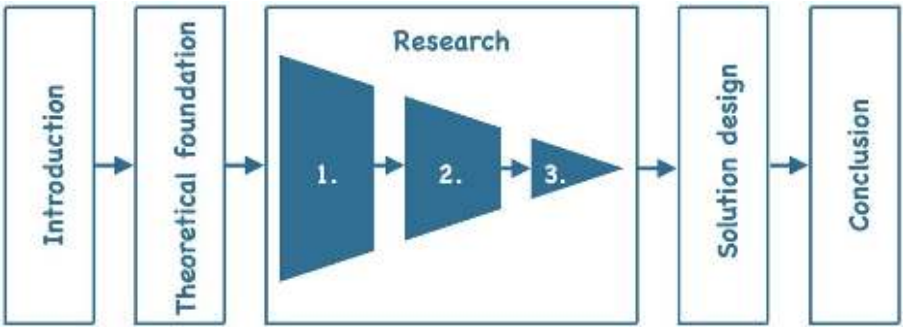

Figure 3: Thesis methodology (Author)

The Figure 3 shows the thesis methodology flowchart which represents the sequence of steps for achieving the main thesis objectives. The theoretical foundation is first and key part of any work. Since it allows to gain a basic knowledge about the Blockchain technology before starting the deep analysis in the following chapters.

The next major part of thesis work deals with empirical research, which is targeted to verify the usability of the Blockchain technology for the project management domain. The performed empirical research within this thesis used a combination of qualitative and quantitative forms of analysis in order to collect relevant data needed to produce the main thesis output. The final step of the research is an evaluation of the 8 proposed use cases of using Blockchain technology for project management area. The evaluation results serve as a justification for the following solution design part. The detailed explanation of the empirical research workflow and qualitative and quantitative approaches used within this work is available in the separate sub-chapter devoted to empirical research realization.

The solution design part proposes the blockchain-based solution for managing projects in accordance with the key Blockchain technology and Project management principles. The designed solution is presented in the form of set of concept models which allows to graphically demonstrate the structure and functionality of the most suitable case of use Blockchain technology for project management purpose from the different perspectives.

2.1 Empirical research realization

There is a sufficient amount of blockchain-based services which are already in use in other significant areas. The Blockchain's potential for the project management domain has not

been fully recognized up to now. The empirical research was chosen as the most appropriate method how to properly verify if there is at least one suitable case of use the Blockchain technology for the project management purposes.

In this thesis work, performed empirical research consists of a set of systematic and some iterative activities which are needed for the creation of innovative knowledge in the form of the conceptually designed solution. The resulting solution will describe the way of the application of the Blockchain technology for the specific project management purposes. The mentioned research's activities are following qualitative and quantitative forms of processing collected data: analysis and synthesis in order to classify the collected data, abstraction and analogy for mapping of obtained results, induction and questionnaire survey for formulation and evaluation of innovative knowledge.

The Figure 4 below describes the research workflow by introducing its main research phases. Each individual phase is composed of several research activities. They are also organized in specific order to obtain more accurate results.

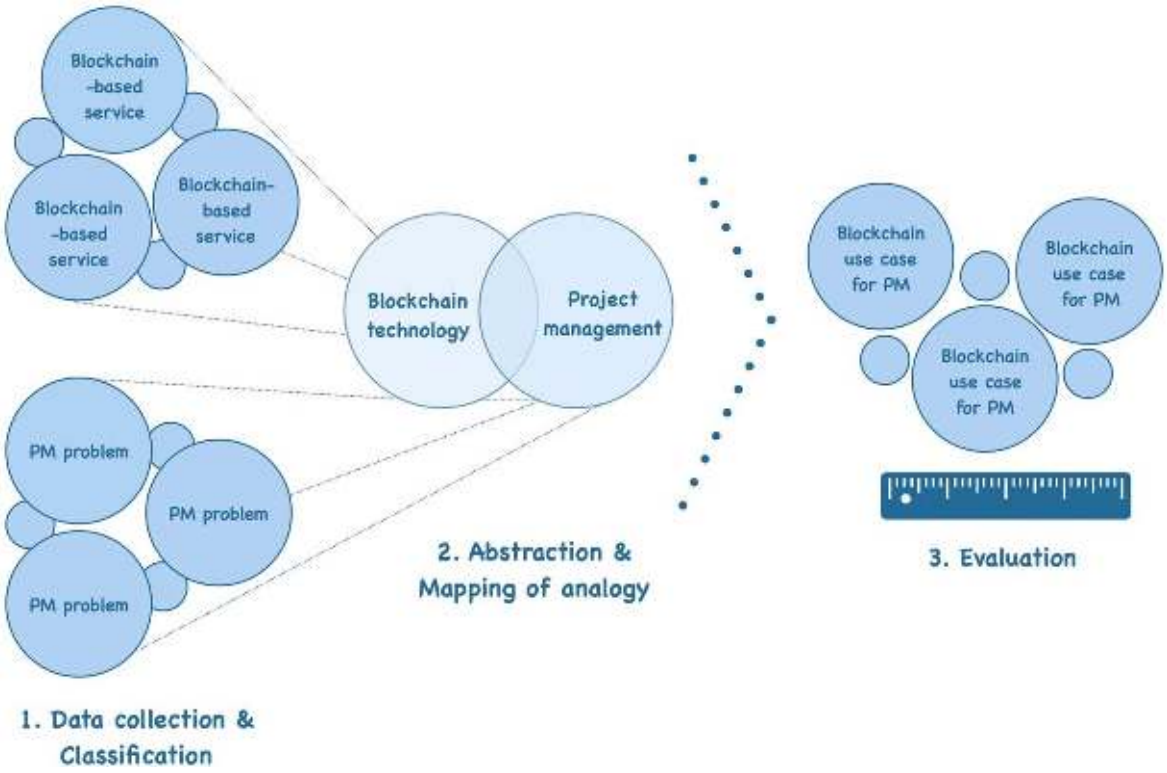

Figure 4: Research workflow (Author)

The research phases are following:

1. **Data collection & Classification**
   Data collection consists of internet research for all existing blockchain-based services implemented in various areas across the whole world. Blockchain-based services are described by accurate explanation of the functionality and area where it is in use. The same action was performed for identification of the actual project management problems and needs with the use of reliable sources of information. During this step the first sample was created, which has been further analysed

during classification process. A sorted and categorized list of available blockchain-based is one of the main outputs from this phase and serves as a general overview of the functional and technological capabilities of the Blockchain together with the needs and requirements that it solves.

2. **Abstraction & Mapping of analogy**

   Abstraction is targeted at identifying the blockchain-based services categories applicable to project management needs. It was done through the mapping of analogy, exactly between the particular blockchain-based services categories and project management problems. The mapping was made based on the author's observations and practices gained through analysis of project management problems, principles and requirements. Here, the analysed sample significantly shrank. All applicable blockchain-based services categories are justified by the clarification of how and where it can be applied in the project management area. In this step, alternative Blockchain use cases came into existence.

   The insights gained from identification part were also used for the formulation of the use cases for Blockchain technology in project management domain. There each identified potential use case was explained in detail including: description of the functionality, problems that it solves and benefits of using.

3. **Evaluation**

   At the beginning of this stage the preliminary check was performed to determine whether the proposed use cases are not out of scope of the PMBOK knowledge areas. Afterwards, the proposed use cases were evaluated by experts from the project management field.

   The evaluation performed within the research is composed of the following steps:

   1) definition of the universal set of evaluation criteria for all proposed use cases;
   2) creation of online questionnaire with the aid of Google Forms;
   3) evaluation by experts;
   4) interpretation of the obtained results;
   5) finalization.

   The main output of this phase and of the research at all is the attained knowledge in the form of the most viable and technically feasible Blockchain use case. Based on this output the designed solution is proposed in the next part of the thesis devoted to solution design.

3 Blockchain technology

The 21st century is a technology era. In such an era technologies are everywhere. Firstly, they changed the way we connect, now it is about significant improvement changes in business operations, customer requirements and day-to-day lives at all. The technologies allow us to do things faster and smarter, to make progress more efficiently than even before. With the increasing level of modernization people tend to be more open to changes and accepting new innovative technologies. Today one of such technological advancements is the revolutionary Blockchain technology which is commonly associated with Bitcoin and other cryptocurrencies. The creation of cryptocurrencies is just the very first use case of Blockchain technology as various applications were developed on the basis of the Blockchain technology. For the last three years the Blockchain technology is the most buzzworthy topic. Because there is still a lot of enthusiasm and transformative potential about Blockchain alongside with scepticism and uncertainty.

The subject of this chapter is to create the theoretical basis needed for the understanding of the topic and for further analysis in the practical part of the thesis work. This chapter introduces Blockchain technology, describes its fundamental underlying principles, presents 3 types of Blockchain networks and the differentiation between them and explains how the Blockchain technology works. The current state of the technology is also reviewed within this theoretical part of the thesis.

3.1 What is Blockchain technology?

There are many different definitions of the Blockchain technology because the term is ambiguous as it has different meanings depending on the context. An experienced banking professional Daniel Drescher provides the following summarizing definition of the technology in his book "Blockchain Basics":

"The Blockchain is a purely distributed peer-to-peer system of ledgers that utilizes a software unit that consists of an algorithm, which negotiates the informational content of ordered and connected blocks of data together with cryptographic and security technologies in order to achieve and maintain its integrity" (Drescher, 2017, p. 35).

Drescher also refers to the following context references for breaking down the term in order to deeply explain the key characteristics of the Blockchain technology (Drescher, 2017, p. 33):

- a part of purely distributed peer-to-peer system,
- a data structure,
- an algorithm,
- a cryptographic and security technologies.

In the following sections the Blockchain technology is explained in-depth in accordance with specified context references. In this thesis work the Bitcoin network was used as an example to explain technical aspects of Blockchain technology. Since Bitcoin is the first and one of the time tested and honoured implementation of the Blockchain which has been used worldwide by millions since March of 2010 (Peterson, 2014).

3.1.1 A part of purely distributed peer-to-peer system

Today people associate the Blockchain technology with purely distributed peer-to-peer systems. But actually it is quite wrong because the Blockchain technology is not in itself the system. The Blockchain technology is a suite of technologies (specific data structure, algorithm, cryptographic and security technologies) which are served as a software unit that is a part of purely distributed peer-to-peer networking. Initially the Blockchain technology was invented as a tool serving for achieving and maintaining integrity in decentralized distributed Peer-to-peer systems (Drescher, 2017, p. 34).

What is a peer-to-peer system (P2P)? The P2P network is a distributed application architecture that consists of individual computers called nodes, which make their computational resources (processing, power, storage capacity or information distribution) directly available to one another (Drescher, 2017, p. 23). The advantage of P2P system is the ability to allow users to interact directly with each other instead of interacting indirectly through middlemen (Drescher, 2017, p. 25). By replacing middlemen, the P2P systems allow users to increase interaction processing speed and to reduce the cost which can significantly reshape many industries (Drescher, 2017, p. 25). The P2P systems are categorized in two broad categories: centralized and decentralized (Vu et al., 2010, p.12). Centralized P2P system has central node that are in charge of control and coordination the interaction between other peer nodes inside the network. The second type is fully decentralized P2P system that is considered as purely distributed. Decentralized P2P system is public, because it is open for anyone. There is no central point of control and "*all nodes perform the same tasks by acting both as providers and consumers of resources and services*" (Drescher, 2017, p. 23). The decentralized P2P system is more inherently resilient than the centralized one. "*The largest and most successful application of P2P technologies is file sharing with Napster as the pioneer and bittorrent as the most recent evolution of the architecture*" (Antonopoulos, 2014, p. 139).

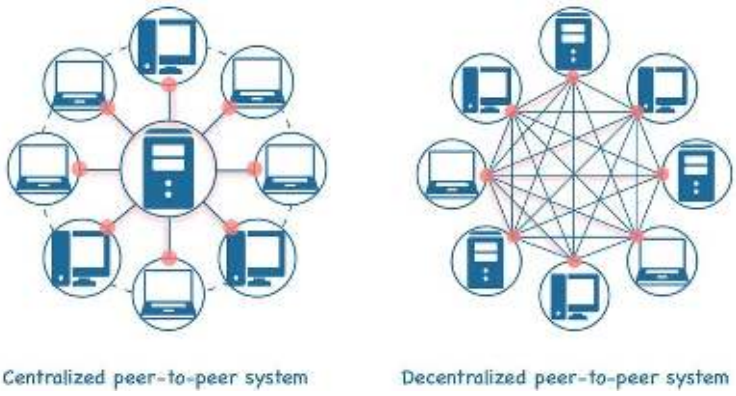

Figure 5: Types of P2P systems
(adapted from Vu et al., 2010, p. 16 and p. 23)

The major concerns of purely distributed P2P computing are integrity and trust:

- Integrity means "*safe, complete, consist, correct, free of errors and corruption*" (Drescher, 2017, p. 30);
- Trust is a belief in an honest interaction without evidence and investigations.

The original idea of Blockchain technology is to solve the major problems of decentralized P2P systems related to integrity and trust to enable people honestly and confidently interact without risk (Drescher, 2017, p. 31). The Blockchain's core characteristics "*can be only achieved and maintained by a flat, decentralized P2P consensus architecture*" (Antonopoulos, 2014, p. 139). In 2009 the Bitcoin Blockchain first introduced the solution of this problem for financial industry by launching a public, open-source P2P payment network with a digital form of money named cryptocurrency.

3.1.1.1 Types of the Blockchain

The first Blockchain solution named Bitcoin was launched as a public and open-source. It means that the source code is available for everyone. After a certain lapse of time the code was copied, modified and updated by many crypto-enthusiasts in order to create other cryptocurrencies. Then the second popular Blockchain platform after Bitcoin named Ethereum enabled realization of self-executed Smart contracts, the popularity of Blockchain technology rapidly raised in the business area. Several companies, enterprises and governments realized that they could use the core idea of distributed ledger technology for their own purposes. This way two permissioned types of Blockchain came into existence: Private Blockchain and Consortium or Federated Blockchain (Buterin, 2015). Today there are three main types of Blockchain networks, they are presented on the Figure 6.

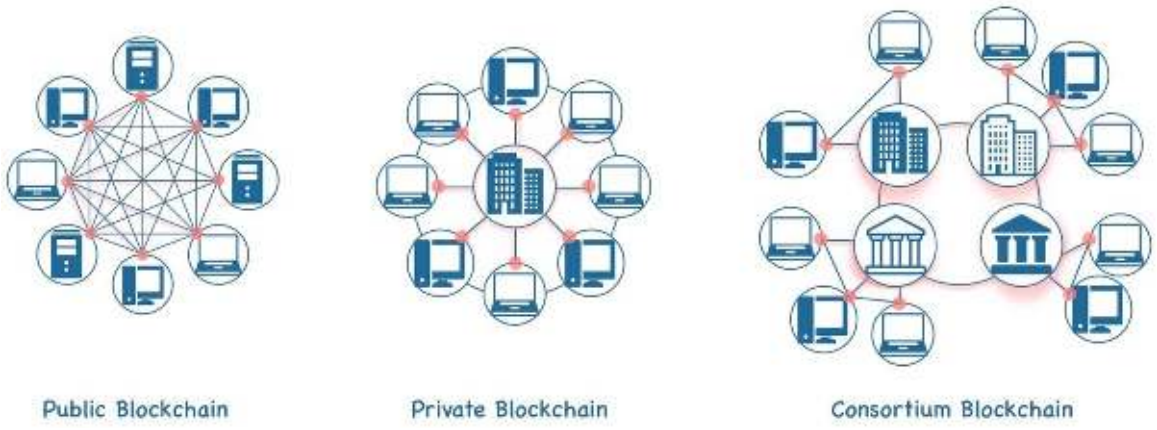

Figure 6: Types of Blockchain (adapted from Applicature, 2018)

What is the difference between public and permissioned types of Blockchain, if all they have some similar properties? Such as following:

- P2P network, where each participant maintains their own copy of shared distributed ledger of digitally signed transactions;
- Copy of the distributed ledger synchronizes through specific protocol referred to special consensus algorithm;

- Certain immutability guarantees of the distributed ledger.

The differences between Blockchain network types can be further distinguished according to their basic characteristics represented in Table 5 located below.

Table 5: Types of Blockchain networks (adapted from Quirante, 2018)

Characteristics	Public Blockchain	Private Blockchain	Consortium Blockchain
Access	*Open-accessed*	*Permissioned*	*Permissioned*
Participants	• *Anyone* • *Anonymous*	• *Individual or single organization* • *Known identities*	• *Group of individuals or organisations* • *Known identities*
Management of permissions	• *No permission management*	• *One central node who manage and control accesses of other participants*	• *All members are in charge of permission management*
Rights	• *Anyone reads* • *Anyone writes*	• *Write rights centralized* • *Read rights may be public or restricted*	• *Write require consensus of several participants* • *Read rights may be public or restricted*
Security	*Consensus mechanisms (PoW, PoS etc.)*	• *Pre-approved participants* • *Voting/multi-party consensus*	• *Pre-approved participants* • *Voting/multi-party consensus*
Transaction speed	• *Slow* • *Transaction per more than 10 minutes*	• *Lighter and faster* • *3-5 transactions per second*	• *Lighter and faster* • *3-5 transactions per second*
Scalability	*Hardly scalable*	*Superiorly scalable*	*Superiorly scalable*
Examples	• *Bitcoin* • *Ethereum* • *Litecoin*	• *Bankchain* • *Monax* • *Hyperledger*	• *R3's Corda for banking institutions* • *EWF for the energy sector* • *B3i for the insurance industry*

As Table 5 indicates public and permissioned types of Blockchain have certain differences resulted by permissions properties, which are also implicated in security mechanisms and transaction speed. Given the apparent differences between Blockchain types, each type has particular advantages and disadvantages.

Today there is some criticism about term Blockchain in context of permissioned distributed ledger. Because it is highly controversial and disputed, as the initial idea of Blockchain is to maintain the honest public P2P network without permissions and any central authority. Due to its open and permission free nature, the public Blockchain hold huge potential to disrupt and reshape many industries that depend on services of intermediate parties. In comparison to public Blockchain the permissioned types can hardly be called "self-sustainable ecosystem", so that they are more considered as a part of distributed ledger technologies than Blockchain. In following chapters of this thesis work the term Blockchain is used for public Blockchain, private and consortium types of Blockchain are hereinafter referred to as distributed ledger technologies.

On the other hand, Blockchain is still in its early stages and its future is unclear yet. "*Many argue that private or consortium Blockchains might suffer the fate of Intranets in the 1990's, when private companies built their own private LANs or WANs instead of using the public Internet and all the services, but has more or less become obsolete especially with the advent of SAAS in the Web2*" (BlockchainHub, 2019a).

Blockchain network on example of Bitcoin

In order to explain how the public Blockchain network operates, this thesis work introduces the basic principles of the Bitcoin network on an example of an extended Bitcoin Network.

The Bitcoin network is a distributed decentralized P2P payment network which carries out managing transactions and the issuing of bitcoins collectively by all nodes included in the network in order to operate without any central authority (Bitcoin.org, 2019a). In the context of Blockchain a node is an individual device or group of devices that runs Blockchain's software in order to maintain the Blockchain network. As was already mentioned in the previous section all nodes have equal rights within a purely distributed P2P network. The same works for Bitcoin network, where nodes are also equal. However, "*they can take different roles depending on the functionality they are supporting*" (Antonopoulos, 2014, p. 140). Therefore, each node inside the Bitcoin network based on its functionality can perform some or all of 5 main roles: Network routing node, Full Blockchain, Miner and Wallet, Protocol Server (Antonopoulos, 2014, p. 140). The Table 6 contains accurate description of each node role.

Table 6: Node's roles inside Bitcoin network (Antonopoulos, 2014, p. 140)

Role	Description
	*Validation and propagation of transactions and blocks, discovering and maintaining connections to peers.*
	*Maintaining the full and up-to-date copy of the Bitcoin history of all transactions. However, within Bitcoin network the other nodes exist, that maintain only a subset of the Blockchain history and validate transactions using a method called Simplified Payment Verification (SPV). These nodes are called Lightweight nodes.*
	*Miner solves hard computational mining task for creating and including the new blocks into general ledger in order to maintain the consensus inside the network. The term mining is further explained in the next chapters Blockchain data structure and Blockchain algorithm. Nodes called Lightweight nodes perform mining actions being included into mining pool since the mining pool is connected to the mining server that has "Full Blockchain" role.*
	*Providing wallet services by storing private key. The clarification of the term private key is available in thesis chapter named Blockchain algorithm.*
 	*Running essential Bitcoin's specialized mining pool protocol and lightweight. Stratum protocol is used for mining and lightweight client access protocol.*

Based on the combination of 5 main roles defined above there are most common node types represented within the extended Bitcoin network at the Figure 7. The extended Bitcoin network is the overall network that includes nodes running specialized protocols as well as the bitcoin P2P protocol, pool mining protocols, the Stratum protocol and any other related protocols connecting the components of the Bitcoin system (Antonopoulos, 2014, p. 140).

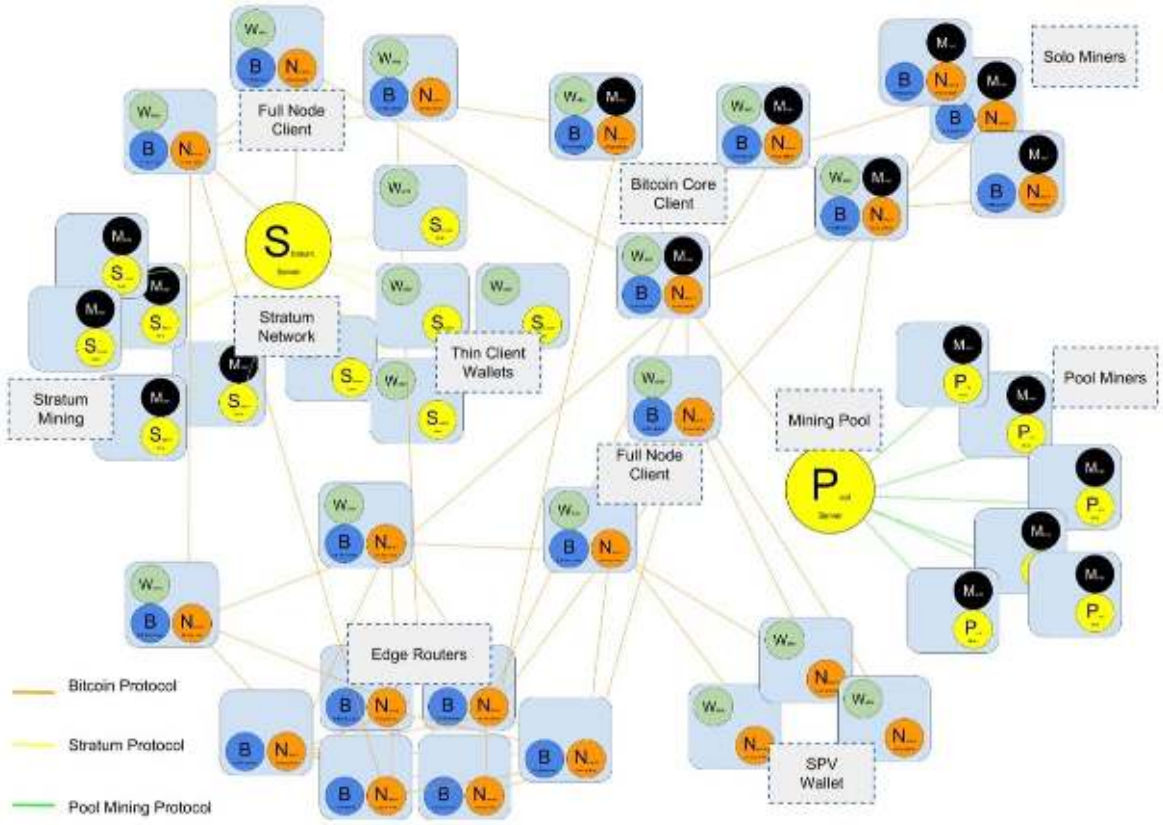

Figure 7: The extended Bitcoin network showing various node types, gateways and protocols (Antonopoulos, 2014, p. 143)

The extended Bitcoin network presented above includes various common types of Bitcoin nodes together with other important network elements, such as: gateway servers, edge routers, mining pool, pool miners, wallet clients and the Bitcoin, Stratum and Pool protocols used to connect the nodes to each other.

3.1.2 Blockchain data structure

Blockchain can be described as a data structure which holds transactional records in the form of ordered back-linked chain of blocks (Antonopoulos, 2014, p. 163). It can be visualised as a linear structure starting with the "genesis" block and continuing with every new block added (Antonopoulos, 2014, p. 166). Every single block collects some number of transactional records in accordance with the limit of the block size. Each newly added block within the Blockchain refers through the hash inside the block header to the predecessor, known as the "parent" block (Antonopoulos, 2014, p. 163). The meaning of the term "hash" is defined in chapter named *Terminology* in the introductory part of the thesis. The sequence of linking blocks to its parent creates the chain which goes back to the very first created "genesis" block. Owing to the existence of parent block linking, data modification in the blocks is is practically unfeasible. Any modification to the transaction inside the block makes the hash value in the following block to be invalid, and as a result it has impact on the subsequent blocks in the Blockchain. That fact makes the Blockchain's deep history immutable (Antonopoulos, 2014, p. 164).

Blockchain data structure on example of Bitcoin

The Figure 8 is a graphic representation of how Blockchain data structure can be implemented on the example of Bitcoin network. According to Bitcoin Book, "*block is a container data structure that aggregates transactions for inclusion in the public ledger, the Blockchain*" (GitHub, 2018). Above all, individual block is made of a header and transactions which largely occupies the space inside the block.

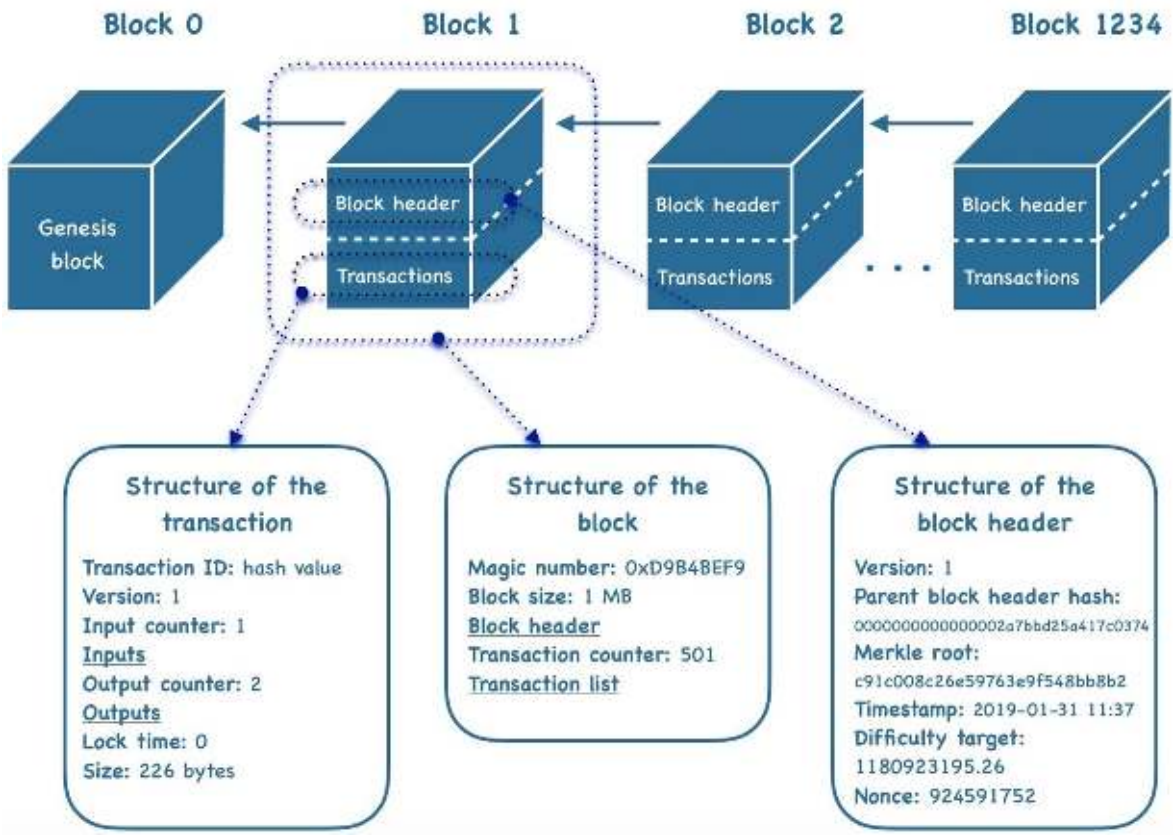

Figure 8: Blockchain data structure (adapted from Singhal et al., 2018, pp.159-165)

Each block is structured as follows:

- **Magic numbe**r – A constant value served as a Blockchain network identifier which allows to understand where the start of the block is and where the end is (Vaidya, 2016).
- **Block size** – A fixed limit of a block capacity for filling up with transactions. The size of each block in Bitcoin network is limited to 1 MB from the beginning and till today (Bitcoin wiki, 2018). In May 2015 was a heavy debate on the matter of increasing the limit to 2 MB (Clifford, 2017). On closure of this debate was agreed that changes of bitcoin's consensus rules will require a hard fork (Bitcoin wiki, 2018). *The hard fork is a software upgrade that introduces a new rule to the network that isn't compatible with the older version of the software* (Castor, 2017). In that case two versions of the software cannot exist together concurrently within the same Blockchain network. Such upgrade requires all participant nodes of the Blockchain network to upgrade the software to the new version in order to continue

participating on the Blockchain network (Parah, 2018). Accordingly, the block size limit wasn't still changed.

- **Block header** - The block header structure is made up of metadata and individually explained in paragraph below.
- **Transaction counter** – A value representing a total number of transactions contained in block (Vaidya, 2016). In Bitcoin block is more than 500 transactions on average (Antonopoulos, 2014, p. 164).
- **Transaction list** – Only verified transactions are gathered into blocks in the form of array. Transactions within Blockchain can be structured differently, it depends on the network purposes and requirements. There are two types of Bitcoin transaction: normal and coinbase. A normal transaction is the act of transferring measurable value between owners (Drescher, 2017, p.65). The coinbase one is a generation transaction, that is always first in the block and always is created by a miner (Bitcoin.org, 2019b). Each normal Bitcoin transaction consists of transaction id, metadata, inputs and outputs. Figure 8 represents basic fields of the Bitcoin normal transaction, that are explained in detail below:
    - Transaction ID – A hash value of the transaction itself, that is served as identification number of the transaction (Kotcher, 2019);
    - Version – A numeric value, that specifies the transaction format version;
    - Lock time – *"A Unix timestamp or block number, that define the earliest time that a transaction can be added to the Blockchain"* (Antonopoulos, 2014, pp. 113-114)*;*
    - Size – A numeric value representing transaction size in bytes;
    - Input counter – A number of input entries included into transaction;
    - Input – A variable value specifying collection of inputs. One transaction can have one or more inputs, the same works for the output;
    - Output counter – A number of input entries included into transaction;
    - Output – A variable value specifying collection of outputs;

  Bitcoin transactions are not encrypted, so they are visible in the Blockchain and can be easily viewed in human legible terms trough Block chain browser (Bitcoin wiki, 2019). Below there is an example of the real Bitcoin transaction with one input and two outputs, that was included in the Bitcoin Blockchain on 19 February of 2014. As it can be seen from the Figure 9 the transaction id is highlighted in red, transaction's metadata are in yellow, transaction's input is coloured green, and transaction' outputs are blue.

```
{
"txid":"90b18aa54288ec610d83ff1abe90f10d8ca87fb6411a72b2e56a169fdc9b0219",
"version":1,
"locktime":0,

"vin":[
 {
  "txid":"18798f8795ded46c3086f48d5bdabe10e1755524b43912320b81ef547b2f939a,
  "vout":0,
  "sequence":4294967295,
  "n":0,
  "scriptSig":{
  "hex":"483045022100c1efcad5cdcc0dcf7c2a79d9e1566523af9c7229c78ef71ee8b6300ab59aa63d02201f
        e27c3e6374dd3a5425a577d9ca6ad8ff079800175ef9a44475bc98bcef21cf0121023b027d54ce8b6c7
        30e0d5833f73aec6a5bae4efe04f57d2864a6a7df2af56e46","asm":"3045022100c1efcad5cdcc0dc
        f7c2a79d9e1566523af9c7229c78ef71ee8b6300ab59aa63c02201fe27c3e6374dd3a5425a577d9ca6a
        d8ff079800175ef9a44475bc98bcef21cf[ALL]023b027d54ce8b6c730e0d5833f73aec6a5bae4efe04
        f57d2864a6a7df2af56e46"
  },
  "addr":"1SqpaRRvdX8HpqRUzq42v5CMPEcFDXV27Q",
  "valueSat":168400000000,
  "value":1684,
  "doubleSpentTxID":null
 }
],

"vout":[
 {
  "value":"5.93100000",
  "n":0,
  "scriptPubKey":
   {
   "hex":"76a9144b358739fc7984b8101278988beba0cc00867adc88ac",
   "asm":"OP_DUP OP_HASH160 4b358739fc7984b8101278988beba0cc00867adc OP_EQUALVERIFYOP_CHECKSIG",
   "addresses":["17rfobSZ8Dj61c8sanhzzR76ADMjWYYpCP"],
   "type":"pubkeyhash"
    },
  "spentTxId":"717b2f3e1b872aebe0cc64434dd0be9ccfa29d9f077c0f65bbaaa4a65fcc3b7d",
  "spentIndex":3,
  "spentHeight":286801
  },

 {
  "value":"1678.06900000",
  "n":1,
  "scriptPubKey"
   {
   "hex":"76a91455368b388ccfe22a3f837c9eee93d053460db33988ac",
   "asm":"OP_DUP OP_HASH160 55368b388ccfe22a3f837c9eee93d053460db339 OP_EQUALVERIFY OP_CHECKSIG",
   "addresses":["18mZn5VXoxcb6MbNKQj17bX4qYxNEU7SDe"],
   "type":"pubkeyhash"
    },
  "spentTxId":"4982fa325c725749b63a883bc73e2c684d1502ada1c7076fb69b  634c3ae5b0a3",
  "spentIndex":0,
  "spentHeight":288896}
 ],

"blockhash":"000000000000000bf3856e067ec21f4c30a8a859cc7ed7f2de9a2b579200639",
"blockheight":286731,
"confirmations":274884,
"time":1392828428,
"blocktime":1392828428,
"valueOut":1684,
"size":226,
"valueIn":1684,
"fees":0
}
```


Figure 9: Bitcoin transaction example (BlockExplorer.com, 2019)

As it was already indicated above, the block header is made up of metadata which can be divided into three sets (Antonopoulos, 2014, p. 164). The structure of the block header is also presented on the Figure 8, detailed specifications of its essential elements are as follows:

1. Reference metadata for connecting each block with its predecessor:

- **Version** – A number which represents block version needed to track software or protocol upgrades (Antonopoulos, 2014, p. 165).
- **Parent block header hash** – A hash value served as a reference to the previous block hash for connecting blocks inside the chain (Antonopoulos, 2014, p. 165). Actually it's a digital fingerprint made by hashing only header of the block two times with use of a cryptographic algorithm (Antonopoulos, 2014, p. 165).

2. Metadata for mining competition:
   - **Timestamp** – A Unix timestamp with approximated time of block creation. Timestamp representing block time is accurate only to within an hour or two. "*An added feature of this field is to make it more difficult to hash the block and hence more difficult to hack it"* (Vaidya, 2016).
     Difficulty target – A numeric value representing the current difficulty in mining blocks of Bitcoin Blockchain. The adjustments are based on the time it took to mine the previous 2016 blocks and its need to aim at 2 week intervals between adjustments (Antonopoulos, 2014, p. 199). By rising or increasing difficulty target on regular base the Bitcoin protocol ensure 10 minutes' average time of block generation with regard on number of miners (Antonopoulos, 2014, p. 200). In Bitcoin network miners attempt to solve the mining puzzle by producing the hashes of the block header in order to find the hash is equal or lower than to the given difficulty target. The process of solving mining puzzle is called Proof of Work algorithm. Therefore, difficulty target affects how long it takes to find a solution to the Proof of Work algorithm (Antonopoulos, 2014, p. 199). The Proof of Work is more closely described in section named *Blockchain algorithm*.
   - **Nonce** – A number value used to vary outputs of cryptographic algorithm by adding at the end of the input data (Antonopoulos, 2014, p. 195). In case of Bitcoin nonce is added to the end of block header for getting a hash that is lower that difficulty target. It always starts with 0 and rises incrementally till the mining puzzle is solved or till some other miner solves the mining puzzle.

3. Merkle root tree metadata:
   - **Merkle root** – A hash value called Merkle root is an overall digital fingerprint of the entire set of transactions inside the block used for efficient process of transaction verification. "*A Merkle tree, known as binary hash tree, is a data structure used for efficiently summarizing and verifying the integrity of large sets of data*" (Antonopoulos, 2014, p. 170). Within Bitcoin Blockchain "*a Merkle tree is constructed by recursively hashing pairs of nodes until there is only one hash, called the Merkle root"* (Antonopoulos, 2014, p. 170). The Figure 10 located below demonstrates the Merkle tree built from 16 transactions. To verify if a specific transaction is included in a particular block there is a need to use logarithmic function of each node hashes to produce a Merkle tree path for linking specific transaction with to the root (Antonopoulos, 2014, p. 172). The Figure 10 also represents Merkle tree path used to prove inclusion of the T_A transaction.

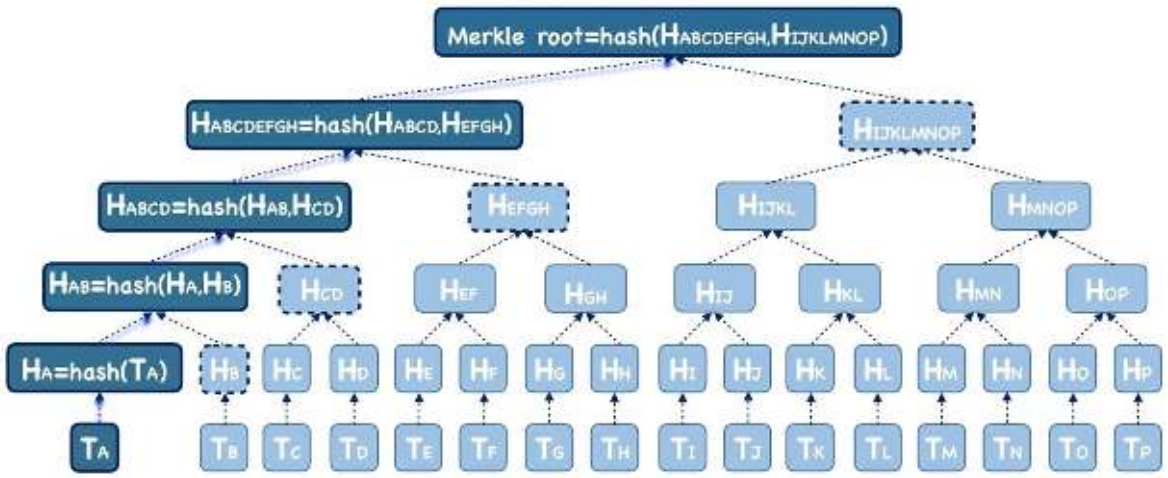

Figure 10: Merkle tree for 16 transactions (adapted from Antonopoulos, 2014, p.173)

The Blockchain technology data structure is far more complex than it might seem at first glance. The visualization of the back-linked chain of blocks at the beginning of this section is just a plain representation of how the data are structured inside the Blockchain. There are several interconnections between blocks and their included transactions. These connections are hard to graphically illustrate with a picture or scheme. The Blockchain data operate under a consensus algorithm governed by the Blockchain protocol and on the base of the Blockchain network created by suite of distributed computer devices. The following chapters deals with explanation of other essential elements of Blockchain technology such as Blockchain algorithm and Blockchain network.

3.1.3 Blockchain algorithm

The main idea of Blockchain technology is a self-sustainable ecosystem that ensures trust, accountability and transparency across the distributed network. But how is it possible to ensure trustworthy storage of information and process operation within distributed decentralized system without any credible middleman's authority? There has to be some kind of incentivization mechanism for keeping such self-sustainable system alive alongside with consensus among all participants of the network (Singhal et al., 2018, p. 130). The Blockchain's incentivization mechanism comes from game theory, under which the Blockchain system should be designed as a game where the participants get the most benefit if they play honestly by the set of specific rules (Singhal et al., 2018, p. 131). This mechanism is called consensus algorithm which serves as an instruction determining the order of events in Blockchain to achieve an agreement on the same state of a Blockchain among all participating distributed systems called nodes (Lisk Academy, 2019). The consensus algorithm is kept in Blockchain consensus protocol to synchronize all the nodes on Blockchain network with each other and to prevent exploitation of the system (Lisk Academy, 2019).

Under the Blockchain data structure, grouping transactions into blocks is needed to guarantee that *"every transaction gets broadcasted to the whole network and every node in the network casts a vote on those individual transactions"* (Singhal et al., 2018, p. 130).

For these reasons "*the consensus is required on a block by block basis*" (Singhal et al., 2018, p. 130). Therefore, the consensus algorithm is essentially in charge of proper execution of the main processes related to the transaction lifecycle and generation of blocks. Because within Blockchain it serves as an instrument for a random node selection which first executes the validation of the coming block and gets the reward for the work performed. The important thing is that the consensus algorithm is suggested fairly and transparently for the all network participants.

Different Blockchain networks may use different consensus algorithms. It primarily depends on the Blockchain's data structure as well as on the purpose of such distributed peer-to-peer network. There were many of Blockchain's consensus algorithms invented in the past decade. Scholars from Chonnam National University, Giang-Truong Nguyen and Kyungbaek Kim presented the summary of the existing consensus algorithms used in Blockchain in their survey paper published in Journal of Information Processing Systems in February of 2018 (Nguyen and Kim, 2018, pp. 122-123).

Blockchain algorithm on example of Bitcoin

In Bitcoin, the consensus is achieved through proper incentive techniques called mining" (Singhal et al., 2018, p. 22). In context of Blockchain technology, mining is intentionally resource-intensive computational process of transaction verification and inclusion them into blocks for adding to the public distributed ledger (Yaga, et al., 2018, p. 23). Bitcoin mining operates in compliance with Proof of Work (PoW) protocol. For the better understanding of the Bitcoin's consensus algorithm it's essential to understand the terms *user and mining node* that are defined in *Terminology* chapter at the introductory part of this thesis work. Under the PoW protocol, "mine" the block means to find a solution to the PoW algorithm for making the block valid (Antonopoulos, 2014, p. 192). The PoW algorithm lies in repeatedly producing the hash of the block header by iterative changing Nonce parameter used to vary hash outputs until the resulting hash complies Difficulty target requirements. The hash of the block header must be equal or lower that the actual Difficulty target defined in the PoW protocol. "*At the current difficulty in the Bitcoin network, miners have to try quadrillions of times before finding a nonce that results in a low enough block header hash*" (Antonopoulos, 2014, p. 195). However, the average time of mining new block is 10 minutes (Antonopoulos, 2014, p. 3). The mining node which proposes the new valid block first to the Blockchain network, would be rewarded for the performed mining activities in Bitcoins. But just in case if the other network participants accept the proposed block as valid and store it within their own copy of Bitcoin's distributed general ledger. Thereby the accepted valid block is chained to other and all transactions included in the block are considered as complete.

A Figure 11 below represents the way how the Blockchain consensus algorithm actually works on an example of the transaction lifecycle and block generation inside the Bitcoin network.

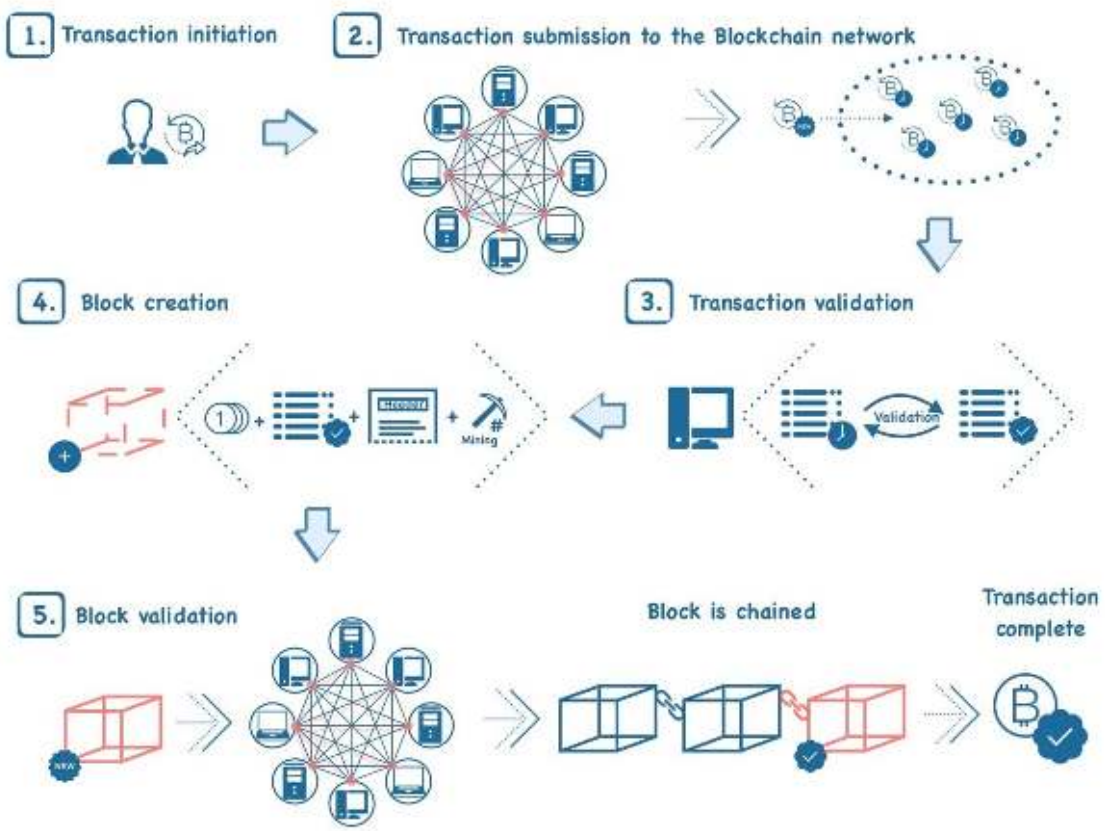

Figure 11: Bitcoin transaction lifecycle (adapted from PwC, 2018a)

1) **Transaction initiation** - The user (who uses Bitcoin network as a service) issues a request for performing a transaction, in which it clearly defines a transaction value, recipient's address.

2) **Transaction submission to the Blockchain network** – As a transaction is submitted by the user it propagates through nodes (who operates Bitcoin software in order to maintain the network) across the Bitcoin network. After the transaction is stored within a pool of unverified transactions, where it is waiting for to be included into the block (Yaga, et al., 2018, p. 24).

3) **Transaction validation** – The mining node select the set of unspent transactions to include them into block "*by applying a priority metric to each transaction and adding the highest priority transactions first*" (Antonopoulos, 2014, p. 184). Transactions are prioritized by their age and input value: older and high-value transactions are more prioritized over newer and small-value transactions (Antonopoulos, 2014, p. 184). Then the mining node checks the transaction against a long checklist of consensus criteria. The main validity control is based on reviewing all the history of transactions with their own copy of Blockchain in order to confirm or not that the transaction is legal, not malicious or double spent. At the end of the transaction validation process the validated transaction is included or not into the block.

4) **Block creation** – In this stage the mining node constructs a block by performing following actions:
   - Add the first transaction in a block named *generation transaction* needed for getting rewards for the work performed. To construct the generation transaction, the miner needs to firstly calculate the transaction fee. The difference between the total input amount and total output values (of all transactions added to the block) works as transaction fee for the Bitcoin miner (Antonopoulos, 2014, p. 188). As a next step the miner calculates the reward for the mining of new block by using the block's height. After the summation of these two values the miner gets a total reward value for performing the work which is subsequently used for the creation of the coinbase transaction. As it was already mentioned before the *coinbase* or *generation transaction* has quite a different structure than the normal one. The main differences are that there is no transaction hash reference and Output index is also set to zero (Antonopoulos, 2014, p. 189).
   - Validated transactions are combined to form a new block. Within a block approximately 500 transactions are stored in accordance with the 1 MB fixed size of each block.
   - Build the block header. The mining node needs to fill six essential fields in order to construct the block header: Version, Parent block header hash, Merkle root, Timestamp, Difficulty target and Nonce. The structure of block header was already explained in *Blockchain data structure* section.
   - In the last step mining node must prove itself to facilitate block creation by "*finding a solution to the PoW algorithm that makes the block valid*" (Antonopoulos, 2014, p. 192).

5) **Block validation** – As soon as mining node solves the PoW task, the miner gets the right to publish the new block to the network. The newly published block is then sent out to other mining nodes across the Bitcoin network. Other nodes need to check the validity of a block by checking the block format, hash of the previous block, and validity of all transactions included to the block. The nodes may not accept a block if it's something wrong with it (Yaga, et al., 2018, p. 19). Then invalid blocks are easily detected and rejected, *"because it is difficult to compute a valid block, but computationally easy to verify one"* (Yaga, et al., 2018, p. 23). If everything is all right, the mining nodes accept the published block as the latest block of the chain and store it within their own copy of Bitcoin's general ledger. After that the transaction can be considered as complete.

3.1.4 Cryptographic and security technologies

The Blockchain technology is designed in a way in which smartly combines several technologies, computing concepts and security mechanisms to safely transfer digital unit without any trustful third parties. In comparison with traditional systems electronic transactions within Blockchain are protected through cryptographic mechanisms instead of a central repository (Yaga et al., 2018, iv).

Blockchain utilizes the following cryptographic mechanisms:

- Asymmetric-key cryptography to securely transfer the value within the Blockchain system;
- Digital signatures for linking transactions to the owners of private keys;
- Cryptographic hashing extensively applied on Blockchain-data-structure to "*make it a very change-sensitive data store*" (Drescher, 2017, p.120).

3.1.4.1 Asymmetric-key cryptography & Digital signatures

The main concept of asymmetric-key cryptography or public key cryptography is a form of encryption used to secure interaction between users in any insecure communication channel. The asymmetric key cryptography uses pairs of keys to protect the interaction of users, each should have their own pair of key. The first one is published for anyone to use, therefore it's called "public key". The second one must always stay secret and kept carefully hidden by its owner, therefore it's called "private key". The private key is used for decryption of messages received. Below there is a simple schema representing the general idea of asymmetric cryptosystem.

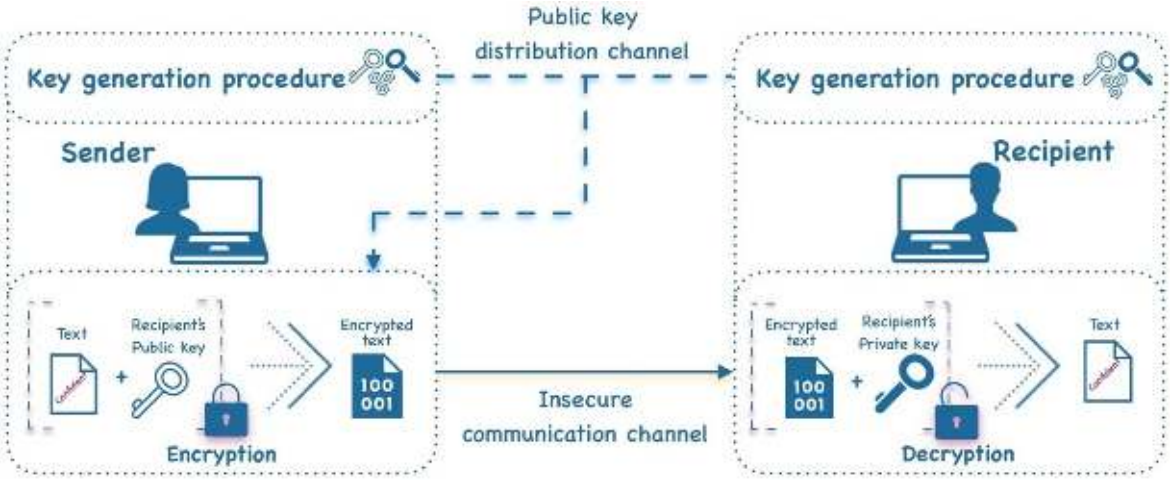

Figure 12: General idea of Asymmetric key cryptography (adapted from Forouzan, 2008)

In many Blockchain systems the public key is calculated from the private key using elliptic curve multiplication (ECDSA), which is irreversible (Antonopoulos, 2014, p. 63). The fact that public key is derived from private indicates the mathematical relationship between both keys. Based on this relationship the digital signatures generated on the base of private key can be validated against the public key without revealing the private key (Antonopoulos, 2014, p. 62).

The asymmetric-key cryptography is utilized in Blockchain systems in several ways in order to provide decentralized trust and control, ownership attestation and the cryptographic-proof security model (Antonopoulos, 2014, p. 61):

- private key for digital signing transactions to safely sent the message/value,
- public key for verification of digital signatures generated with private key to receive the message/value,

- verification if the user transferring the value is in possession of the private key capable of signing the value,
- public key as well as hash of public key for addressing transactions with one-to-many approach for pseudonymity (Yaga et al., 2018, p. 14).

As for Bitcoin Blockchain in simple terms "*the public key is used to receive bitcoins, and the private key is used to sign transactions to spend bitcoins"* (Antonopoulos, 2014, p. 62).

3.1.4.2 Cryptographic hash

As it is also defined in the chapter *Terminology* the cryptographic hash is an asymmetric function that converts an input data (letters and numbers) of any size into an encrypted output of a relative short fixed-length (Singhal et al., 2018, p. 56). The output value returned by hash function is named as fingerprint or simply hash. Cryptographic hash functions serve their main purposes using their following core features (Singhal et al., 2018, p. 56):

- input value can be string of any size, output value is always fixed-length;
- hash value is easily computable for any input value;
- the same input value processed by the same hash function always provides the same hash output value;
- any small change of input value considerably affects the output hash value;
- hashing as algorithm is collision resistant, it's computably impossible to find two or many different input values that produce the same output hash.
- it is impossible to decipher the input value from its hash, except trying for all possible inputs.

Secure Hash Algorithm with an output size of 256 bits (SHA -256) is hashing algorithm used in many Blockchain systems as well as in Bitcoin. It is compatible with various software platforms and operating systems, in general "*SHA-256 is supported on OS X 10.5+ and Windows XP SP3+"* (Global sign, 2018). For input of any size the cryptographic algorithm SHA-256 generates a unique fixed-length output of 32 characters (8 bytes). The Table 7 located below contains examples of inputs and hash outputs after processing by SHA-256. As it can be seen from the table added dash, dot or even space completely change the output hash. The hash algorithm SHA-256 is also case sensitive, that is demonstrated by the second and third examples.

As mentioned previously in *Blockchain data structure* chapter, within the Blockchain technology the cryptographic hash is used mainly for:

- creating fingerprint of entire content of a block called Merkle tree root;
- for creating a unique hash of a block header in accordance with Blockchain's consensus algorithm;
- as a reference for linking each block with previous one.

Table 7: Hashing examples for SHA-256 (Author)

№	Input value	Output hash value
1.	*Blockchain*	*625da44e4eaf58d61cf048d168aa6f5e492dea166d8bb54ec06c30de07db57e1*
2.	*Block-chain*	*37cb9b3ca6ae5853d5a377d26f3bda1958f766f4c4ddcdf728898b5b1d4e5631*
3.	*Block chain*	*8a347e1afd785d0c88500c16fbaa234029bd41d9af5ee2c7da6cf98c5b8af3e7*
4.	*block chain*	*0b198ecb2a56b9f4765f9d9e0a8adb2c6d8231f17b2ed8abce9fb12512937c78*
5.	*Blocks are chained.*	*b879d4b1af5a01754989f5442d748214945ccd2ae4424e50edb887db01041036*
6.	*Blocks are chained*	*d37292be35c9cf329fea87fd2e988c72166a47ef377a94cbffa352f68401b439*
7.	*321*	*8d23cf6c86e834a7aa6eded54c26ce2bb2e74903538c61bdd5d2197997ab2f72*

Any small change of transaction inside the block subsequently cause a change of Merkle tree root value inside the block, change the block header hash and as a result destroy the connection between blocks. These changes will be immediately visible to other participants of the Blockchain. The purpose of hash function not only to secure the data stored in Blockchain but to ensure the integrity and transparency of the data at all levels of the data structure.

3.1.4.3 Impact of quantum computing on cryptographic algorithms used in Blockchain technology

Recent researches proved that the advent of quantum computers make present cryptographic algorithms obsolete, especially such as the public key encryption (RSA, ElGamal, ECC and DSA) and symmetric key algorithms (3DES, AES) (Mavroeidis, et al., 2018, p.8). A quantum computer is a computer that performs computational actions using quantum-mechanical phenomena, such as superposition and entanglement (Gershenfeld and Chuang, 1998). Almost all public key algorithms used today rely on the computational complexity of integer factorization (RSA) or work on solving discrete logarithms (DSA signatures and ElGamal encryption) (Mavroeidis, et al., 2018, p. 408). Both these problems have similar mathematical structure and can be broken with Shor's algorithm that can be executed on quantum computer (Mavroeidis, et al., 2018, p. 408). "*The family of hash functions suffer from a similar problem as symmetric key algorithms since their security depends on a fixed output length*" and can be easily decipher by Grover's quantum algorithm (Mavroeidis, et al., 2018, p. 408). *So many of the present hash algorithms are also disqualified for use in the quantum era"* (Mavroeidis, et al., 2018, p. 408).

As it was already indicated in previous sections many Blockchain systems utilize Elliptic Curve Cryptography (ECDSA) within public key cryptography. "*ECDSA uses modification*

of discrete logarithm problem that makes it equally weak against quantum computers" (Mavroeidis, et al., 2018, p. 408). Many Blockchain systems also use SHA-256 as a hashing method needed to secure the data stored. "*At the present the hashing algorithm SHA-256 remain still quantum resistant*" as opposed to ECDSA (Mavroeidis, et al., 2018, p. 408). Because families of hashing algorithms SHA-2 and SHA-3 have longer outputs therefore they remain to stay secure against quantum attacks so far (Mavroeidis, et al., 2018, p. 408).

With the advent of quantum computing era the public key cryptographic algorithms utilized within most Blockchain technologies need to be replaced with a strongest one quantum resistant cryptographic system. The hashing algorithms and Merkle trees that are in charge of creation of Blockchain data structure are much sustainable to quantum computing attacks. But sooner or later it can be also broken if a power quantum computer become a reality. There is still time to prepare for this oncoming quantum computing trend. In case of ignoring or neglecting, the existence of Blockchain technology came into question as well as several innovations and existing services based on public key cryptography.

Post-quantum cryptography

A physical sciences laboratory and a non-regulatory agency of the United States Department of Commerce, The National Institute of Standards and Technology (NIST) in April 2016 published in its report a list of cryptographic algorithms families, that have been proposed to be resistant for both classical and quantum computers as well as focused on public key algorithms (Chen, et al., 2016, p. 3). "*These families include those based on lattices, codes, and multivariate polynomials, hashes as well as others that do not fall into the 4 previous families*" (Chen, et al., 2016, p.3). Most of the identified quantum resistant algorithms have larger key sizes than currently used public key cryptographic algorithms (Chen, et al., 2016, p.3). This may result the main challenge that should be overcome for successful replacement vulnerable public key algorithms with the new quantum resistant encryption methods (Chen, et al., 2016, p.3). This challenge consists of the possible changes of the various internet protocols (Transport Layer Security and Internet Key Exchange) (Chen, et al., 2016, p.3).

After in December 2016, NIST initiated a post-quantum cryptography standardization project, that is aimed on "*to solicit, evaluate, and standardize one or more quantum-resistant public-key cryptographic algorithms, that are secure against both quantum and classical computers, and can interoperate with existing communications protocols and networks*" (NIST, 2019b). In January 2019, within the status report NIST announced the results of the first round of submissions. From the 82 algorithms received for consideration, the 69 algorithms met the acceptance criteria and were submitted as first-round candidates (Gorjan, et al., 2019, p. 1). After evaluation and selection process NIST revealed 26 winning algorithms advancing to the post-quantum cryptography semi-final (Gorjan, et al., 2019, p. 2). Currently, NIST is reviewing second-round submissions. "*These 26 algorithms are the ones we are considering for potential standardization, and for the next 12 months we are requesting that the cryptography community focus on analysing their performance*," said NIST mathematician Dustin Moody (NIST, 2019a). In 2020, NIST plans to select algorithms for participation in a final round and then select a small number of winning candidates for standardization (Gorjan, et al., 2019., p.18).

3.2 Blockchain advantages and limitations

The Blockchain technology as well as each technological solution has its own advantages and disadvantages. These characteristics differentiate the technology from other existing solutions, help to better understand technology capabilities and limitations and at the same time they serve as determining factors to make a choice between new revolutionary solutions and traditional database systems. This thesis chapter deals with explanation of the Blockchain technology advantages and limitations in two steps: by introducing underlying principles of public Blockchain in order to explain the differences against traditional storage systems and by comparison of public Blockchain, distributed ledger technologies and traditional storage solutions presented in table for clarity.

3.2.1 Blockchain technology underlying principles

As it was already indicated in the Introduction chapter of this thesis the Blockchain technology is different from existing traditional solutions and the difference can be explained by it is 5 fundamental underlying principles. These underlying principles can be also used to explain the biggest advantages of Blockchain systems against existing traditional solutions.

Consistent, forgery resistant distributed ledger

Once a transaction is recorded into Blockchain, it cannot be deleted or lost as almost each participant of the Blockchain network has own copy of it. There is no single authority that controls and manages the data stored. If some nodes in the system lost their copies of transactions history, it will not result in total data loss or the loss of significant part of the data. As there are always other nodes who also maintains their own copies of the entire history of Blockchain transactions. The nodes of Blockchain system cannot lose their copies of the data all at once. It is practically impossible to occur for the reasons of large quantity of nodes and their geographical distribution.

Auditable, persistent, immutable and irreversible records

The more blocks are added to the chain, the immutability of the data stored within Blockchain increases (Singhal et al., 2018, p. 125). As transactions added to the block are cryptographically linked with each other trough Merkle root hash as well as each block is also cryptographically connected with his predecessor based on the hash of the block header. This feature makes very difficult to falsify or delete recorded transactions. Because in case of changing or deleting one transaction it impacts on Merkle root hash and subsequently disrupt the connection between blocks. Therefore, it is practically unfeasible to change the data of several blocks without disrupting connection between them. So, a transaction stored in Blockchain remains forever in the system (Singhal et al., 2018, p. 125). Alongside with persistence and immutability the back-linking between the blocks through hashes till the first genesis block allows to ensure auditability of the Blockchain system.

Resilient democratic peer-to-peer transmission

The Blockchain is completely open and public. Anyone can join the system, there is no any central authority which manages access to the system. All participants have equal rights in any situation that allow them to communicate directly instead through central authority. There is no node in the system that is more powerful than the other. (Singhal et al., 2018, p. 125). Each node stores and forwards the data to all other nodes inside the system under equal conditions (Iansiti and Lakhani, 2017, p. 119). Main decisions regarding transaction validation, data storing and rewards are made upon consensus reached by majority of participants involved. By its purely distributed nature the Blockchain system is resilient enough to network failures, unavailability of particular participant nodes, network latency and packet drops, etc (Singhal et al., 2018, p. 125).

Transparency with pseudonymity

Transactions are public and anyone has access to the complete history of transactions executed within Blockchain. All transactions are visible with the associated details such as value, time, sender's and recipient's addresses. Each Blockchain user "*has a unique 30-plus-character alphanumeric address that identifies it*" (Iansiti and Lakhani, 2017, p. 119). Furthermore, the Blockchain system always provides the choice to the users to be identified or to stay anonymous. Performing transactions on pseudonym basis is executed by providing public key hash instead of public key all time to receive the payment. That approach of keeping public key anonymous is recommended by Satoshi Nakamoto in Bitcoin's white paper (Nakamoto, 2008, p. 6).

Computational logic

"Blockchain transactions can be tied to computational logic and in essence programmed" (Iansiti and Lakhani, 2017, p. 119). Users can set up algorithms and rules that automatically trigger transactions between nodes that automatically executed when the certain conditions are met. This option is called as smart contract, that was firstly launched by Ethereum Blockchain.

As it can be noticed, all mentioned underlying principles of Blockchain technology come from the Blockchain's suite of technologies: purely distributed P2P network, specific data structure "chain of blocks", specific Proof of Work consensus algorithm and security and cryptographic technologies.

3.2.2 Blockchain vs. traditional system and distributed ledger technologies

When it comes to advantages and limitations of particular technology it's always better to analyse it in comparison with the other existing solutions. It helps to fully understand the meaning of each advantageous and limited aspects of analysed technology. This thesis work provides a detailed comparison of Blockchain technology with traditional systems and distributed ledger technologies.

The comparison performed within this thesis were conducted in a way to enable the analysis under several important aspects for showing the main differences between solutions. Each

analysed option needs to be clarified for preventing possible misunderstanding and misconceptions:

- Existing database solutions are relational and non-relational types of databases,
- Blockchain technology means public Blockchain,
- Distributed ledger technologies refer to permissioned types of Blockchain (private and consortium).

Based on the comparison presented in the Table 8 each analysed solution has its own advantages and limitations. Blockchain is able to maintain the trust and integrity of open self-sustainable systems by consensus mechanism and providing high protection of the data stored. For the business purposes Blockchain is a not appropriate option due to: legal and regulatory uncertainty, absence of confidentiality, slow performance and enormous consumption of energy and resources that have direct impact on the cost as well as. Therefore, relational and non-relational types of databases and distributed ledger technologies seem as more suitable solutions. Distributed ledger technologies against existing database solutions have several benefits such as stronger security protection, transparency, auditability and integrity of the data. However, relational and non-relational databases are still faster, with low level of redundancy and without storage constraints.

Each analysed solution is able to provide several benefits. The choice regarding the implementation always should depend on the purposes and needs of the particular organization or individual. One thing is certain: while considering about using Blockchain technology it is important to take into account the absence of data confidentiality and its possible implications on the services that would be provided within the system. Will data openness serve a useful purposes of the system in practice and what can it bring? Is there any added value?

Table 8: Comparison of Blockchain technology versus traditional database and distributed ledger technologies (adapted from Mölken, 2018, p.139-156)

Aspect	Existing database solutions	Blockchain technology	Distributed ledger technologies
Architecture	✓ *client-server network architecture*	✓ *decentralized distributed P2P network architecture*	✓ *centralized distributed P2P network architecture*
Infrastructure & Cost	✓ *admin maintains the server (performance and configuration)* + *lower cost for server administration*	✓ *infrastructure cost is shared among all network participants* - *higher cost for developing the solution and rewarding miners for maintaining the system*	+ *miners no need to be rewarded* - *higher cost for developing, support and maintenance for distributed ledger technologies software*
Management	✓ *centralized (users are dependent on the*	✓ *decentralized (users act without*	✓ *centralized (users allowed to access by*

Aspect	Existing database solutions	Blockchain technology	Distributed ledger technologies
	admins that delegate access and grant various permissions to the users)	*any central administration but under specific consensus mechanism)*	*central authority and act under specific consensus mechanism)*
Disintermediation	✓ *depended on intermediaries (admin services, operating organization etc.)* ✓ *stored procedures are enabled (works similarly as Smart contract);*	✓ *fully disintermediated* ✓ *smart contracts enabled*	✓ *partly disintermediated (operating organization)* ✓ *smart contracts enabled*
Range of user capabilities	✓ *permissions are defined by admin* ✓ *all users can CRUD (Create, Read, Update, Delete)*	✓ *all users have equal rights* ✓ *all can read and write only*	✓ *permissions are defined by central authority* ✓ *users can only read or read and write*
Replications & Data recovery	✓ *master-slave and multi-master* - *backups for restoring the data relevant at a certain moment (in case of a large-scale databases it is a duplication of a huge amount of data)*	✓ *full replication of block on every peer* +*storage of all entries that has ever been entered*	✓ *full replication of block on every peer* +*storage of all entries that has ever been entered*
Data	+ *high confidentiality (only required data and only after authentication with credentials)* - *low transparency and auditability (no history of changes and ownership of records)* - *low integrity (users rely on honest administration services, updating and deleting*	- *zero confidentiality (data is available for everyone)* + *high transparency and auditability (entire history of all records with owners, changes are not possible)* + *high integrity (due to cryptographic security and consensus mechanism users can be sure that the data stored is*	✓ *middle-level of confidentiality (data are available for everyone who has access)* + *high transparency and auditability (entire history of all records with owners, changes are not possible)* + *high integrity (due to cryptographic security and consensus mechanism users can be sure that*

Aspect	Existing database solutions	Blockchain technology	Distributed ledger technologies
	information creates a point of failure and numerous inefficiencies)	*uncorrupted and unaltered)*	*the data stored is uncorrupted and unaltered)*
Security	✓ *security ensured by safety of the main server and access policy distribution system* - *inability to prevent malicious activity*	✓ *security ensured by physical remoteness of all nodes, cryptographic encryption and consensus mechanism during storing information to the system* + *high level of fault tolerance* + *ability to withstand interference from malicious actors* + *mathematical guarantees of irreversibility of records* - *main threat on security is 51% percent attack (more than half the nodes tell a lie during transaction validation)*	✓ *security ensured by physical remoteness of all allowed nodes and access policy distribution system,* ✓ *the security promises as good as the honesty of the entities validating the transactions* - *there are no mathematical guarantees behind the irreversibility of transactions* + *the 51% attack does not apply, as it can be easily detectable and can involve legal action*
System redundancy	+ *low redundancy (transaction validation is processed once or twice)*	- *high redundancy (transaction validation is processed by all peers included into network)*	✓ *middle level of redundancy (transaction validation is processed by pre-defined set of nodes participating in consensus mechanism)*

Aspect	Existing database solutions	Blockchain technology	Distributed ledger technologies
Storage limitation	+ *there is no limitation of how many transaction can be stored in a given time*	- *limited by consensus mechanism (time needed for validation of transactions included into to published block)*	✓ *Partly limited by consensus mechanism*
Performance	+ *fast* + *immediate user response*	- *slow (affected by signature verification, consensus mechanism, redundancy, network size)* - *transaction takes approximately 10-60 minutes (it depend on the network load)*	✓ *relatively fast* ✓ *time to reach consensus is much less than in Blockchain*
Scalability	+ *easily scalable*	- *hardly scalable*	✓ *significantly better scalable*
Energy and resource consumption	+ *low*	- *high (due to mining activities required by consensus mechanism)* - *miner need to have powerful hardware to perform intensive computational process to solve mining task*	+ *low* ✓ *there is no mining activities, as the consensus mechanism can be based on voting system*
Integration	+ *well integrated with the other existing solutions*	- *integration may require significant changes or full replacement of existing solution* - *it's necessary to resolve the problems related to data transmission and blocking of platform cooperation by using standard protocols*	- *integration may require significant changes or full replacement of existing solution* - *it's necessary to resolve the problems related to data transmission and blocking of platform cooperation by using standard protocols*

Aspect	Existing database solutions	Blockchain technology	Distributed ledger technologies
		- *currently, there are no standard protocols for integrating IT systems and cloud applications with the Blockchain*	- *currently, there are no standard protocols for integrating IT systems and cloud applications with the distributed ledger technologies*
Regulatory	✓ *in accordance with regulatory requirements depended on context and implementation*	- *in some countries several public crypto Blockchains are considered is illegal due to smart contracts, intellectual property, liability and compliance (GDPR).* - *anonymization and decentralization are in conflict with many traditional regulatory requirements* - *enforceability of smart contracts that are not legally defined*	✓ regulated by *special framework* developed especially for distributed ledger technologies ✓ *service level agreement between the ledger operator and the participants, which would establish liability, including limitations of liability*
Cultural adoption	+ *culturally adopted* + *a wide range of solution developed in accordance with methodologies and experience from different disciplines* + *tested by a large number of people* + *plenty of useful information available on internet*	✓ *cultural challenge: it's a new way of doing things* ✓ *implementation will be associated with overcoming the fear of change* - *presently, people are not yet ready to use Blockchain* - *people associate Blockchain with cryptocurrencies, fast enrichment, drugs, hacking and crime*	✓ *cultural challenge: it's a new way of doing things* ✓ *implementation will be associated with overcoming the fear of change* + *several companies already adopted this solution in various areas (finance, supply chain and digital identity)*

3.3 Current state of the Blockchain technology

At the early beginning of the 2019 the magazine of Massachusetts Institute of Technology (MIT) announced (Orcutt, 2019):

> "*In 2017, Blockchain technology was a revolution that was supposed to disrupt the global financial system. In 2018, it was a disappointment*" in a view of the significant fall in the value of almost all blockchain-based cryptocurrencies and virtual assets. "*In 2019, it will start to become mundane*". Nonetheless, many innovative-sounding projects are still alive and close to yield desired results. Alongside with it several "*large corporations' (Walmart, Intercontinental exchange and Fidelity Investments) plan to launch major blockchain-based projects in 2019*". Therefore, 2019 purportedly should be "*the year that Blockchain technology finally becomes normal*."

The coming normalization of the Blockchain technology means a significant changing of the ideology and perception of the technology that was given by mainstream notoriety of cryptocurrencies. The 2019 year is such turning point for Blockchain technology, "*with momentum shifting from "Blockchain tourism" and exploration to the building of practical business applications*" (Deloitte, 2018).

3.3.1 Blockchain technology by countries

Today the Blockchain technology is known everywhere around the world as a revolutionary way of providing financial services. However, the first Blockchain implementation Bitcoin has faced with challenges in the form legislative and regulatory boundaries, therefore in some countries the first innovative peer-to-peer payment system is still considered as illegal or restricted.

Table 9: Countries where Bitcoin is still illegal or restricted (Justin B., 2018)

Bitcoin is illegal	Bitcoin is restricted
Afghanistan, Algeria, Bangladesh, Bolivia, Pakistan, Qatar, The Republic of Macedonia, Saudi Arabia, Vanuatu, Vietnam	American Samoa, China, Ecuador, Egypt, India, Indonesia, Morocco, Nepal, Zambia

On the other hand, the countries such as Switzerland, USA, Canada and Australia are not only countries with the strongest Blockchain start up scene but they are also cryptocurrency-friendly countries (Web Desk, 2018). The payments by cryptocurrencies are legally regulated and supported in these countries.

Furthermore, several counties already use the Blockchain technology on a governmental level:

- "*Republic of Chile uses Ethereum Blockchain to track data and finances to ensure accountability, traceability and security*" (Rawal, 2018);

- Estonia is considered as the Blockchain nation and e-government pioneer. Estonia adopted Blockchain for operation Digital IDs and E-Health records (Denbow, 2017);
- Georgia adopted Blockchain technology for implementation the land registry to fight with corruption in the real estate industry (Rawal, 2018);
- Ghana uses Blockchain technology for the land registry.
- *"Singapore is partnering with R3 and a consortium of major financial institutions in the world for a proof-of-concept project to conduct inter-bank transactions using Blockchain technology"* (Rawal, 2018);
- Sweden implemented land registry on the Blockchain basis (Denbow, 2017);
- *"UK uses Blockchain for paying welfare cheques and disbursing student loan"* (Rawal, 2018);
- *"United Arab Emirates (UAE) have plans to be the first blockchain-powered government by 2020"* (Denbow, 2017). The UAE's plans of Blockchain adoption are defined in the Smart Dubai Strategy document.

3.3.2 Blockchain technology by industries

At the end of the 2018 the world's leading research and advisory company Gartner presented the forecast of how the Blockchain technology will evolve until 2030. For understanding Blockchain technology development trajectory, Gartner presented graphical scheme with "Hype Cycle for Blockchain Business". With the aid of Blockchain's hype cycle curve Gartner visually demonstrates the difference between the hype around Blockchain technology and real future perspective.

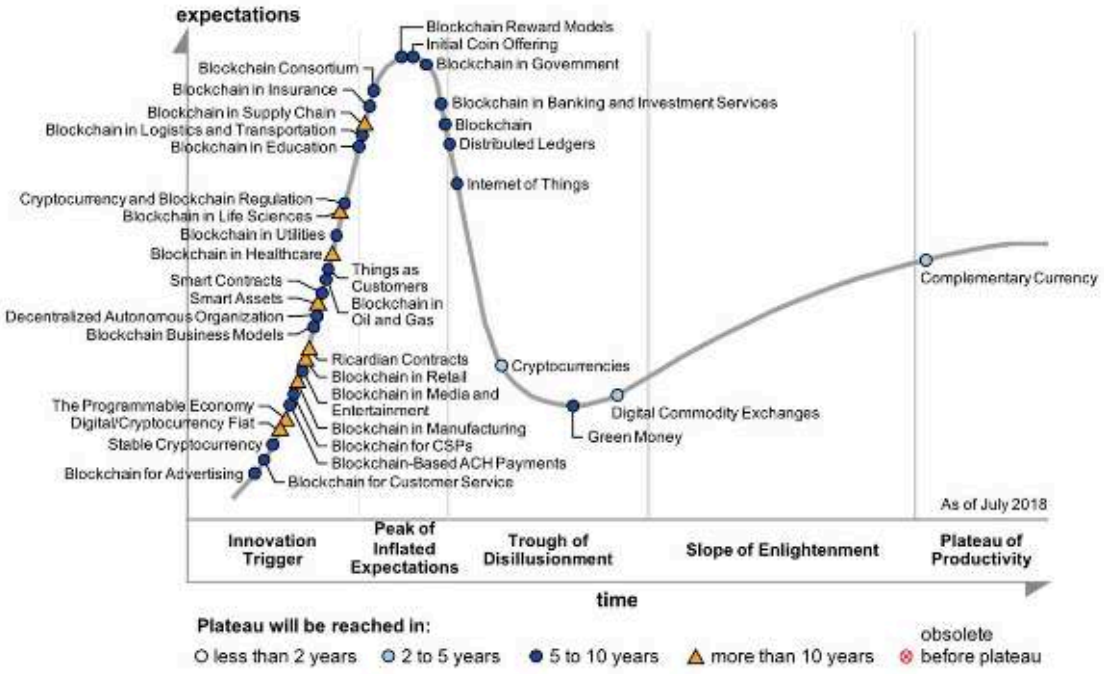

Figure 13: Hype Cycle for Blockchain (Gartner, Inc., 2018c)

As it can be seen from the Figure 13 located below the majority of solutions for several industries are in their nascent stage. For example, Blockchain solutions for manufacturing,

healthcare and supply chain will reach their maturity after more than decade. Regardless of the fact, that several leading companies (IBM, Oracle, Amazon etc.) are ready to provide such solutions (Arnold, 2019) here and now and several successful implementations on the government level described in the previous section. Alongside with it, under Gartner's forecast the Blockchain solutions for financial area would be the first Blockchain solutions that reach the plateau expectedly by 2020-2023. Solutions for other key industries such as logistics and transportation, insurance, oil in gas and many other will be improving till 2028.

3.3.3 Blockchain technology across companies

Today the leading advisory companies such Gartner, Deloitte and PwC recommend in their research and forecast publications to invest in Blockchain technology or "*at very least to keep an eye on it so that they can take advantage of opportunities when they present themselves*" (Deloitte, 2018, p. 7). Therefore, a lot of private and government organization is considering or already made investments in the Blockchain technology for moving with the times in the use of new technologies. But according to the study of one of the most respected newspapers in the Netherlands De Volkskrant "*9 out of 10 initiated Blockchain projects never got past the experiment phase*" (Yilmaz, 2018). The second problem of the initiated Blockchain projects is that the projects are aimed on Blockchain technology utilization within organization instead of focusing "*on areas of friction and outmoded processes that can benefit from the democratization of trust and the ability to more securely verify the authenticity of both B2B and B2C digital transactions*" (Deloitte, 2018, p. 11). Blockchain projects that are focused on solving a valid problem for organization run into problems related to Blockchain technology constraints such as performance and privacy. Despite the presence of these facts, advisors from Deloitte believe that "*the real mistake organizations can make regarding Blockchain right now is to do nothing*" (Deloitte, 2018, p. 7)

Currently for many companies the most optimal and convenient way how to invest in Blockchain technology is to join the existing Blockchain consortiums or to create their own with partner organizations. "*As consortia represent a low-risk effort to stay current on Blockchain trends, learn what competitors are doing, defend against potential new threats, and prepare to implement the technology should they decide to*" (DeFrancesco, 2016). According to the survey performed by Deloitte in April-May of 2018 the majority of the total 1053 respondent companies across seven countries (Canada, USA, Mexico, France, UK, Germany, China) already participate in or will likely join a Blockchain consortium (Deloitte, 2018, p. 13, p. 25). The survey results are presented on Figure 14 located below.

Currently more than 40 Blockchain consortia have been established globally, that are mainly heading in following sectors (Gratzke, Piscini and Schatsky, 2017):

- 26 consortia for Financial sector,
- 10 Cross-sector consortia,
- 3 consortia for Life-science & Health care,
- 1 consortium for Energy & Resources,
- 1 consortium for Public sector.

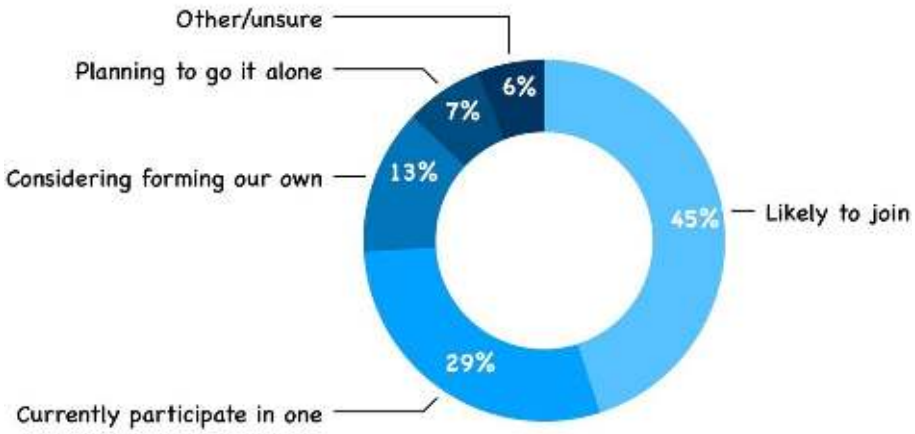

Figure 14: Organization's position on participating in a Blockchain consortium (Deloitte, 2018, p. 25)

The Figure 15 located below represents the biggest Blockchain consortia that include world's leading companies. The consortia such as R3CEV, Ripple and Digital assets holdings are specialized mainly on financial services, the Hyperledger consortium is established as general purpose Blockchain (Trivedi, 2017).

Figure 15: Leading Blockchain consortia include world's leading companies (Trivedi, 2017)

3.3.4 Blockchain technology challenges

The main objective of Blockchain technology is to give transparency, disintermediation, equality, straightforwardness and security protection to every one of its users. In any case, these Blockchain's characteristic traits create a great deal of specialized difficulties and constraints. Slow performance, poor scalability, interoperability, regulation and privacy law issues should be tended to resolution for making the Blockchain technology future more certain. Due to these difficulties it's also seems that the Blockchain technology potential has been over-communicated and its benefits are elusive.

Below there are three main actions, that should be made to overcome the existing obstacles in adoption of Blockchain technology worldwide:

- ✓ *Technological improvements*. Certain technological improvements are needed to resolve low performance, high energy consumption and poor scalability constraints that directly depend on the technological features of the Blockchain technology. The

Blockchain's incentivization mechanism used for ensuring consensus about validity of transactions directly affects the system performance and energy consumption. By optimizing evolution of the consensus algorithm the issues related to performance, energy consumption and scalability can be resolved to a certain extent.

- ✓ *Creation of standards for Blockchain*. The next significant obstacle of the Blockchain technology is its interoperability with other existing solutions as there is no set of standards exists to allow them to interact with each other. The creation of a competent set of standards for the protocols, coding languages, consensus mechanisms and privacy measures is needed to enable easier integration with existing systems and collaboration for enterprises on cooperative application development (Browne, 2018). The standards for Blockchain technology will also need to take all of possible uses of the technology into consideration. Probably, the Blockchain technology standards need to be established individually for each particular area of use.
- ✓ *Creation of satisfactory regulations for Blockchain*. Privacy law issues and the absence of sufficient regulatory policies and norms applicable to the carrying out of the smart contracts. The legislative and regulatory boundaries need to be clearly defined for the how Blockchain transactions should be written, information-sharing process within the system as well as for execution of smart contracts. This way the development of Blockchain technology will be supported from the regulatory side.

Blockchain technology is still fairly new and needs a lot of effort and work for overcoming these biggest challenges to be adopted globally across various areas. There is only question how much time will be required and unsuccessful attempts to be made to address these constraints?

4 Blockchain-based services

With the rapidly rising popularity of the Blockchain technology in the business area the companies, enterprises and governments realized that they could use the core idea of distributed ledger technology for their own purposes. This way the various blockchain-based services had appeared during the last decade. Alongside with the Blockchain technological expansion and progressive adoption, two terms characterizing blockchain-based services had been originated "Blockchain as a Service" and "Decentralized application".

An educational finance news and services website Investopedia gives to the term Blockchain as a Service (BaaS) the following well-described explanation: "*Blockchain as a Service (BaaS) is an offering that allows customers to leverage cloud-based solutions to build, host and use their own Blockchain applications, smart contracts and functions on the Blockchain while the cloud-based service provider manages all the necessary tasks and activities to keep the infrastructure agile and operational"* (Frankenfield, 2018). The BaaS is developed similarly to the concept model of Software as a Service (SaaS). The leading technology companies such as IBM, Intel, Microsoft, Oracle, Amazon, SAP are currently offering through their web pages the BaaS to enterprises as a secured cloud platform (IBM, 2019a; Sawtooth., 2019; Microsoft Azure, 2019; Oracle, 2019; Amazon, 2019; SAP, 2019). Along with them such companies Alibaba, Baidu and several smaller startups are also providing viable BaaS solution (Alibaba, 2019; Baidu, 2019). Today the BaaS solutions give a great opportunity to large and small companies to simply outsource the complex technical work focused on creation and operating the Blockchain network. The usage of BaaS solutions by companies of any size can potentially significantly contribute to adoption and deep penetration of the Blockchain technology across various industries worldwide.

The second term, that has been existing since the advent of P2P networks and was newly popularized by the Ethereum Blockchain is the Decentralized application (DApp) (BlockchainHub, 2019b). DApp is an application that runs on distributed computing systems and don't necessarily need to operate on top of a Blockchain network (BlockchainHub, 2019b). DApp is working on similar principles as a traditional web application, the one main difference lies in the logic of the application background. The simple web application uses special API to connect to a database, instead of it the DApp uses a smart contract for connection and operation with the Blockchain system. However, presently in order to be considered a "decentralized" DApps must meet a few requirements (Khatwani, 2018):

- ✓ **Open source** – the application source code must be available for all;
- ✓ **Decentralized** – the application has to be sufficiently decentralized, data stored within the Blockchain system as a satisfactory option of the way of decentralization;
- ✓ **Algorithm or protocol** – the application must have its own incentivized system which generates tokens or other forms of digital assets for enabling the application to be s self-sustainable;

The benefits of the DApps lies in the advantages of underlying Blockchain technology, that enables to maintain high level security of the data and allows the integration with cryptocurrency as with a form of digital assets.

The growing number of Blockchain networks, consortiums and decentralized applications aroused a need to register the developed opportunities in order to release the power of the Blockchain technology. For these specific purposes HACERA in cooperation with IBM launched the distributed "yellow pages" for Blockchain network in autumn of 2018 (Cuomo, 2018). *"The Unbounded Network provide a decentralized means to register, look up, join and transact across a variety of Blockchain solutions, built to interoperate with all of today's popular distributed ledger technologies, including The Linux Foundation's Hyperledger Fabric, Hyperledger Sawtooth, R3 Corda, EEA Quorum, Stellar Network and more*" (Unbounded - powered by HACERA, 2019). Jerry Cuomo, vice president at IBM Blockchain, wrote in his post in IBM Blockchain Blog that Unbounded Network provides the following key capabilities: (Cuomo, 2018):

- "*reserved naming for networks, applications and consortiums,*
- *the discoverability of Blockchain networks and applications,*
- *a catalogue of domain-specific functions and services,*
- *an independent, open and shared Blockchain backed platform to help the organisations with bootstrapping, launching and growing the communities*".

Currently, more than 400 blockchain-based services are available through the HACERA's Unbounded Network register, that were launched by start-up projects as well as the globally leading companies such as IBM, Intel, Oracle, SAP, Huawei, Xiaomi and other (Unbounded - powered by HACERA, 2019).

Alongside with recently established Unbounded Network register there are also available various research papers and articles describing the current state of the Blockchain technology. These research papers and articles are mostly published by educational institutions, leading technology companies such IBM and global research, advisory and consulting companies such as Gartner, McKensey and Deloitte. The summary statistics included to these publications in majority cases represent:

- number of successfully adopted blockchain-based solutions by industries or countries,
- results of surveys focused on gathering opinions of CIO's and IT people from leading technology companies about coming changes brought by Blockchain revolution,
- forecasts for future and other.

That all is interesting, informative and useful, but not sufficient for the attainment of the objectives of this diploma thesis. The further investigations were needed in order to better understand the Blockchain technology capabilities and functional aspects of the currently offered blockchain-based solutions. The following section of this chapter is focused on further analysis of all existing blockchain-based services that are currently offered across various industries.

4.1 Blockchain-based services research

As it was already described in the *Approach and methods* chapter, in order to achieve the stated goals this diploma thesis deals with particular empirical work performed in the three main stages. The online research was executed under the first stage of the thesis empirical work. The research was focused on collection of information about the blockchain-based services that are currently available on the Internet. The workflow of the online research was organized in the following way:

1) search for all existing blockchain-based services which have already been applied in various areas or existing for now as concept use cases;
2) elimination of duplicates for creation of the list of the blockchain-based services, that are unique by its purposes within particular industry.

The output of the online research is the assembled table of 81 unique blockchain-based services developed in terms of different industries. The complete table with research results due to its size cannot be inserted to the main text of the work. Therefore, for clarity and more comfortable manipulation with the data the table named "Full overview of the existing blockchain-based services" was provided in a digital form as an Excel file attached to this work. The table reflects the list of the available blockchain-based services by the end of 2018. Table consists of the following fields in order to sufficiently describe the services found:

- name of the service,
- service type,
- area,
- description,
- owner of the service / useful link.

The detailed description of the table content is available in the Appendix of this diploma thesis.

Based on the gathered results the following interesting facts were observed:

- The most useful source of the information is IBM Blockchain Blog. The IBM's blog consists of plenty of useful articles and other comprehensive publications about Blockchain technology, implemented blockchain-based solutions and potential use cases (IBM, 2019b).
- In total 81 different blockchain-based services were discovered within the online research.
- 79% of the services found are already existing solutions. Only 21% of the total is created by concept use cases that are waiting for its implementation.
- 27 different areas applying Blockchain technology were identified.
- Top 5 areas of Blockchain application in descending order by the percentage of different types of implemented solutions: Financial sector – 12%, Government sector– 11%, Healthcare industry – 10%, Automotive industry – 9%, Intellectual property rights area – 7%.

- The other identified areas, that are belong to the Top 10 areas of Blockchain application: Enterprise sector –6%, Energy industry – 5%, Insurance industry – 5%, Supply chain area – 4%, Trading industry – 4%.

The assembled list of existing blockchain-based services was used as the base for the further analysis required for classification of the discovered services under the categories. The classification process is described in detail in the following section.

4.2 Classification of the blockchain-based services under categories

The second step of the empirical work conducted within 1. stage is the detailed analysis for the sake of classification of the discovered blockchain-based services under categories. The analysis was performed for deep understanding of the technological capabilities of currently offered blockchain-based solutions and for finding its common features according to their major functional purposes. During the detailed analysis of currently existing blockchain-based services the several valuable options of applying Blockchain technology by companies from various industries were detected:

- ✓ for tracking assets in ways that are not possible with traditional databases,
- ✓ for keeping track of complex things,
- ✓ for storing data securely without point of failure,
- ✓ for secure collaboration with multiple parties involved,
- ✓ for secure collaboration without well-established authority in place.

Taking into account all gathered observations during the analysis of the discovered blockchain-based services was decided to perform classification process in three phases for consistency reasons. The workflow of the classification process executed as the second step of the 1. stage of the thesis empirical work was following:

1. **phase** of the classification process was executed to group the collected blockchain-based services by their main functional purposes. The result of this phase is 23 different categories sorting the blockchain-based services out by their core functionalities. Top 3 categories of the third level by the number of the solutions included are following:
    - Shared storage of transparent, immutable and auditable data for tracking – 12 solutions are 15% of total number of discovered services;
    - Decentralized collaboration platform for sharing economy – 9 solutions are 11% of total number of discovered services;
    - Shared storage of transparent, immutable, auditable and sensitive data – 9 solutions are 11% of total number of discovered services.
2. **phase** of the classification process was focused on additional grouping of the services categories defined in previous stage. The purpose of the second phase of categorization was to reduce the number of determined categories in the 1. phase of categorization by its consolidation. The merging of the third level categories was performed based on the common functional features of the blockchain-based services included into them. This way the 18 categories of the second level arisen.

The reducing of the number of the categories hadn't been such effective as it was expected.

3. **phase** of the classification process was aimed to unite the blockcahin-based services categories of the 2. level in accordance with the utilization of the Blockchain technology key advantage characteristics. The result of this stage is the sorted categories of the 2. level by two new main categories of the 1. level:
   - Decentralized collaboration platform,
   - Shared storage of transparent, immutable and auditable data.

Table 10: Blockchain-based services main categories (Author)

Category 1	Category 2	Category 3	Number of services
Decentralized collaboration platform	*Decentralized collaboration platform for bidding process*	Decentralized collaboration platform for bidding process	2
	Decentralized collaboration platform for claiming and billing services	Decentralized collaboration platform for claiming and billing services	2
	Decentralized collaboration platform for coworking	Decentralized collaboration platform for coworking	5
	Decentralized collaboration platform for digital certification/ notarization	Decentralized collaboration platform for digital certification	1
		Decentralized collaboration platform for digital notarization of existence	2
		Decentralized collaboration platform for digital notarization of ownership	2
	Decentralized collaboration platform for managing policies within entire industry	Decentralized collaboration platform for managing policies within entire industry	1
	Decentralized collaboration platform for secure sharing of information	Decentralized collaboration platform for secure sharing of information	5
	Decentralized collaboration platform for sharing economy	Decentralized collaboration platform for sharing economy	9
	Decentralized collaboration platform for tracking the life-cycle of tokenized assets	Decentralized collaboration platform for tracking the life-cycle of tokenized assets	1
	Decentralized collaboration platform for trading	Decentralized collaboration platform for trading	3

Category 1	Category 2	Category 3	Number of services
	Decentralized collaboration platform for continually inspection	Decentralized collaboration platform for continually inspection	1
	Decentralized collaboration platform for payments without intermediaries	Decentralized collaboration platform for payments without intermediaries	7
	Decentralized collaboration platform for ownership management	Decentralized collaboration platform for ownership management	5
	Decentralized collaboration platform for trustworthy funding	Decentralized collaboration platform for trustworthy funding	2
Shared storage of transparent, immutable and auditable data	*Shared storage of transparent, immutable and auditable data for artificial intelligence market*	Shared storage of transparent, immutable and auditable data for artificial intelligence market	3
	Shared storage of transparent, immutable and auditable data for decentralized execution of commands	Shared storage of transparent, immutable and auditable data for decentralized execution of commands	1
	Shared storage of transparent, immutable, auditable and sensitive data	Shared storage of transparent, immutable, auditable and sensitive data	9
	Shared storage of transparent, immutable, auditable data for tracking/monitoring/ automation	Shared storage of transparent, immutable and auditable data for monitoring conditions	3
		Shared storage of transparent, immutable and auditable data for tracking	12
		Shared storage of transparent, immutable, auditable data for monitoring and automation of resource consumption	1
		Shared storage of transparent, immutable, auditable data for monitoring resource consumption	3
Not classified	*Security platform*	Security platform	1

The complete output of the classification process is the three-level list of blockchain-based services categories presented by the Table 10 located above. The list of existing blockchain-based services applied for categorization procedure is attached to this thesis as the Appendix A. The blockchain-based services categories serve as a structured representation of the core functionalities of the existing blockchain-based solutions together with the overview of problems that it solves. The performed categorization of the available blockchain-based services is one of the main outputs from the 1. stage of the thesis empirical work. Alongside with it, the blockchain-based services categories were used as valuable foundation for verification of the potential of using the Blockchain technology in project management domain. The procedure of the verification is thoroughly described in the next thesis chapters *Blockchain for project management: use cases* and *Evaluation of use cases*.

5 Blockchain for project management: use cases

Since the main aim of the diploma thesis is to analyse the potential of using Blockchain technology for project management purposes, alongside with the analysis of technological and functional capabilities of the Blockchain technology there is also a necessity to analyse the existing project management problems and needs. The identified project management problems will help to better target the Blockchain technology advantages towards to resolution of difficulties aroused during managing projects for satisfaction of the project management needs. Through identified project management problems, a more precise proposal of the potential use cases of applying Blockchain technology in project management area can be made.

The processes of identification of project management problems and potential use cases are explained in detail in the following two sections of this thesis chapter, *Project management problem* and *Identification of the potential use cases*. The main output of these two procedures is the proposal of 8 use cases which are accurately described in the concluding section of this chapter named *Description of the potential use cases*.

5.1 Project management problems

Since 2006 the Project management Institute (PMI) has been conducting the Global Management Survey named PMI Pulse of the Profession to map the global project management trends (PMI, 2018a). Each year the PMI reports within the survey the project management trends based on feedback and insights from project, program, and portfolio managers from a wide range of industries and countries (PMI, 2018a). According to the 2018 edition, the current state of the global project management is described through the following statistics (PMI, 2018a):

- 58% of organizations fully understand the value of project management discipline;
- 62% of organizations globally have a Project Management Office (PMO);
- 93 % of current organizations report uses of standardized project management practices;
- Only 39% of current organizations characterize their project management maturity as high, the other 34% define their project management maturity as medium, 27% consider it as low;
- 40% of organizations are highly investing in technology to better enable project success.

Within the PMI Pulse of the Profession 2018 report there are available statistics describing the projects completed during the last 12 months (between 2017 and 2018) in organizations participated in PMI's survey. The statistics below represents facts describing the success rate of the projects finished worldwide across various industries: (PMI, 2018a):

- 69% of completed projects successfully met the original goals and business intent of the project;
- 57% of projects finished within their initial budgets;
- 52% of projects ended within their initially scheduled times;
- 32% of projects failed project's budget lost;
- 15% of projects were considered as failure.

The statistics presented above shows that despite the almost all organizations are using standardized project management practices and majority of companies is investing in technology and skills development, there are still points of failure in the project management procedures. Together with the successful rate statistics PMI included to the global survey report for the 2018 the project management problems that were considered by participated organizations as the more common project management points of failure (PMI, 2018a):

1. *"change in organization's priorities,*
2. *change in project objectives,*
3. *inaccurate requirements gathering,*
4. *inadequate vision or goal for the project,*
5. *inadequate/poor communication,*
6. *opportunities and risks were not defined,*
7. *inaccurate cost estimates,*
8. *poor change management,*
9. *inadequate sponsor support,*
10. *resource dependency,*
11. *inaccurate task time estimate,*
12. *inexperienced project manager,*
13. *limited/taxed resources,*
14. *inadequate resource forecasting,*
15. *team member procrastination*
16. *task dependency".*

The results of the actual PMI's Global Project Management Survey were used for purposes of this diploma thesis as the one of the main information source about actual project management problems and needs. In order to create the wide-ranging base of currently existing project management difficulties that have potential to cause undesirable consequences on success of the project completion, the other reliable information sources were analyzed. The analysis was performed in context of the first stage of the thesis empirical work. The additional intention of the analysis was selection of the existing project management problems that can be theoretically handled by project management software. The main output of this analysis is the traceability matrix with defined project management problems in the table rows and used information sources in the table columns. As the main sources of information recently published reports were used from project management surveys performed in 2018 by PMI, PwC and Wellingtone PPM Intelligence (PMI, 2018a; PwC, 2018b; Wellingtone PPM Intelligence, 2018). Together with the survey reports the several conference papers available from PMI's Learning Library were also used as valuable information sources about existing project management problems.

Table 11: Traceability matrix with identified project management problems covered by used information sources (Author)

Project management problems	PMI, 2018a	PwC, 2018b	Wellingtone, 2018	Andersen, 2006	Bergerud, 2012	Coventry., 2015	Kumar, 2006	Rever, 2007	Trevino et al., 2008	Aziz, 2015	Stuart, 2014
1. Lack of continuous monitoring and tracking of project objectives in real-time			✓	✓							
2. Insufficient stakeholder awareness	✓	✓	✓								
3. Unclear specification of requirements	✓					✓	✓				
4. Overlapping and duplicating requirements	✓						✓				
5. Unrealistic customer expectations						✓					
6. Poor requirements management	✓	✓					✓				
7. Quickly changing customer requirements	✓	✓				✓					
8. Change of the project scope	✓	✓	✓	✓		✓	✓				
9. Poor quality control		✓						✓			
10. Lack of continuous improvement								✓			
11. Absence of the supplier quality		✓									

Project management problems	PMI, 2018a	PwC, 2018b	Wellingtone, 2018	Andersen, 2006	Bergerud, 2012	Coventry., 2015	Kumar, 2006	Rever, 2007	Trevino et al., 2008	Aziz, 2015	Stuart, 2014
assurance requirements											
12. Inspection over prevention			✓	✓				✓			
13. Different perceptions about quality		✓						✓			
14. Customer dissatisfaction with the quality of project outcomes								✓			
15. Solving a different problem the same way	✓	✓							✓		
16. Lack of awareness and understanding of issue or change	✓	✓	✓	✓							
17. Poor communication about resolving the problem	✓	✓	✓						✓		
18. Insufficient consensus between stakeholders	✓		✓								
19. The cost estimate for the entire project is no reliable	✓	✓			✓						
20. Reduced opportunity to decrease the cost during the project delivery process		✓			✓						
21. Over budgeting	✓				✓						

Project management problems	PMI, 2018a	PwC, 2018b	Wellingtone, 2018	Andersen, 2006	Bergerud, 2012	Coventry., 2015	Kumar, 2006	Rever, 2007	Trevino et al., 2008	Aziz, 2015	Stuart, 2014
22. Cost accounting, not cost analysis		✔			✔						
23. Never ending project				✔						✔	
24. Stakeholders do not realize that the project is over and continue treat it as an active project										✔	
25. Negative perception of project team efforts' for matters that are not their fault or responsibility										✔	
26. No effective utilization of lessons learned from past project			✔						✔		
27. Constantly solving the same problem over and over again		✔							✔		
28. Unmotivated team members	✔	✔	✔								✔
29. Negligence of results – not focused on achieving the team's results	✔										✔
30. Poor team spirit			✔								✔
31. The team is not high performing	✔	✔									

Project management problems	PMI, 2018a	PwC, 2018b	Wellingtone, 2018	Andersen, 2006	Bergerud, 2012	Coventry., 2015	Kumar, 2006	Rever, 2007	Trevino et al., 2008	Aziz, 2015	Stuart, 2014
32. Lack of commitment – team members don't commit or buy in to decisions											✓
33. Avoidance of accountability – unwilling to discuss performance behaviour	✓										✓

The analysis results are presented in the Table 11 placed above. As it can be seen from the Table 11 the thirty three different project management problems were identified. With the aid of the list of the discovered project management problems and defined in previous section blockchain-based services categories the process of identification of Blockchain technology's potential in project management area is performed. The whole procedure performed within this diploma work for the identification of the potential applications of Blockchain technology that can be beneficial in resolving of the existing project management problems is accurately explained in the following section of the fifth thesis chapter.

5.2 Identification of the potential use cases

The implemented process of verification if the Blockchain technology has potential to be applied in project management domain was built on logical and heuristic methods, abstraction and analogy. By classifying the currently available on the market blockchain-based solutions on the market under different categories a certain level of abstraction was gained. The process of classification is explained in detail in the thesis section named *Classification of the blockchain-based services under categories*. The result output of the iterative classification process is grouping of discovered blockchain-based services by their common functional traits as well as by the type of the problems that the solutions resolve. These findings can be considered as the abstract characteristics presenting Blockchain technology capabilities of resolving various problems in practice. Afterwards these findings were used for the analogy method that enables to find fresh insights about problem resolution based on discovering the similarities with existing solutions from the other industries.

In the second stage of the empirical research performed within this diploma thesis the analogy method was applied through the mapping between defined blockchain-based services categories and discovered project management problems. The mapping was made based on similarities of the problems that the defined categories are applicable to resolve. The mapping results are represented by the Table 12 located below.

Table 12: Mapping of the blockchain-based services categories on the identified project management problems (Author)

Blockchain-based services category that resolves the similar problem	**Use case name**	**Project management problems**
Shared storage of transparent, immutable, auditable data for tracking and monitoring →	***1. Scheduling & milestone tracking***	← Lack of continuous monitoring and tracking of project objectives in real-time
Decentralized collaboration platform for coworking →		← Insufficient stakeholder awareness
Shared storage of transparent, immutable, auditable data for tracking and monitoring →	***2. Requirements management***	← Unclear specification of requirements
		← Overlapping and duplicating requirements
		← Unrealistic customer expectations
Decentralized collaboration platform for coworking →		← Poor requirements management
		← Quickly changing customer requirements
		← Change of the project scope
Shared storage of transparent, immutable, auditable data for tracking and monitoring →	***3. Quality management***	← Poor quality control
		← Lack of continuous improvement
		← Absence of the supplier quality assurance requirements
Decentralized collaboration platform for continually inspection →		← Inspection over prevention
Decentralized collaboration platform for coworking →		← Different perceptions about quality
		← Customer dissatisfaction with the quality of project outcomes
Shared storage of transparent, immutable and auditable data for artificial intelligence market →	***4. Issue & Change Management with flexible problem-solving***	← Solving a different problem the same way
Decentralized collaboration platform for coworking →		← Lack of awareness and understanding of issue or change
		← Poor communication about resolving the problem
		← Insufficient consensus between stakeholders

Blockchain-based services category that resolves the similar problem	Use case name	Project management problems
Shared storage of transparent, immutable, auditable data for monitoring and automation of resource consumption →		← The cost estimate for the entire project is no reliable
		← Reduced opportunity to decrease the cost during the project delivery process
Decentralized collaboration platform for payments without intermediaries →	***5. Cost management***	← Over budgeting
Decentralized collaboration platform for continually inspection →		
Shared storage of transparent, immutable and auditable data for artificial intelligence market →		← Cost accounting, not cost analysis
Decentralized collaboration platform for continually inspection →	***6. Project closing***	← Never ending project
		← Stakeholders do not realize that the project is over and continue treat it as an active project
Decentralized collaboration platform for coworking →		← Negative perception of project team efforts' for matters that are not their fault or responsibility
Shared storage of transparent, immutable and auditable data for artificial intelligence market →	***7. Base for lessons learned***	← No effective utilization of lessons learned from past project
Decentralized collaboration platform for managing policies within entire industry →		← Constantly solving the same problem over and over again
Decentralized collaboration platform for tracking the life-cycle of tokenized assets →		← Unmotivated team members
		← Negligence of results – not focused on achieving the team's results
Shared storage of transparent, immutable, auditable data for monitoring and automation →	***8. Rewarding system***	← Poor team spirit
		← The team is not high performing
Decentralized collaboration platform for coworking →		← Lack of commitment – team members don't commit or buy in to decisions
		← Avoidance of accountability – unwilling to discuss performance behaviour

The Table 12 demonstrates that each identified project management problem placed into the third table column is mapped on specific second-level blockchain-based services category located in the first left side table column. The second table column is the column representing the title of connecting relationship created based on combination of included project management problems. The identified relationships also stand for the particular use

case of the application of Blockchain technology that can be potentially beneficial for the project management domain.

As it was already mentioned, the revealed relationships were made based on an analogy from the practical resolution of the similar problems on example of the existing solutions from the other areas. Below is the explanation of the considerations based on which the 8 different potential use cases were analogically identified:

1. **Scheduling and milestone tracking.** The first use case was analogically identified through analysis of the blockchain-based solutions mainly developed for the supply chain area where the guarantee of tracking and tracing of the deliveries is essential part of the business. The same works for the scheduling and milestones tracking within the project management process, since these activities primarily ensure the timely fulfilment of the project goals, objectives and requirements. The actively engaged stakeholders is the one of the top drivers of project success according to the PMI's Global Project Management Survey for 2018 (PMI, 2018a). The involving of the stakeholders into the process of controlling deliveries is the main principle as well as the advantage of the currently existing blockchain-based solutions designed especially for supply chain area.

2. **Requirements management.** The identified use case for requirements management was also influenced by Blockchain solutions for supply chain, where the status data representing the progress of the delivery are used for tracking the fulfillment of the order. The same principle can be borrowed and realized based on Blockchain platform for the requirements management. The key advantages of the Blockchain technology are immutability, transparency and auditability of the data that can be beneficial for this use case. Since all customer expectations about project outcomes need to be specified accurately and historically stored within the requirements log. The dependencies or conflicts of the requirements is the second thing that needs to be maintained within the requirements log. The other useful aspect which the Blockchain technology enables is the smart contract which can be used to ensure traceability of the requirements.

3. **Quality management.** The quality management use case was influenced by Blockchain solution for regulatory compliance and JetData system. The Blockchain solution for regulatory compliance is still existing as a concept use case for now, but it has recognized beneficial potential by various industries. The first regulatory compliance solutions are expected to appear for Financial sector and Healthcare industry in next two years (IBM, 2016; The Brooklyn Project, 2019). The regulatory compliance blockchain-based solution is targeted on continual control instead of relying on periodic short inspections: the regulations are automatically enforced via rules defined in self-executed smart contracts in order to control the events and to ensure that appropriate parties are informed about non-compliant events as they happen (IBM, 2016). The second solution JetData is the blockchain-based global aircraft parts tracking and analytics system that enable to securely "*maintain detailed records about the origins, repairs, maintenance, events and transactions for every aircraft part in inventories worldwide*" (JetData, 2019).

The Quality management Blockchain-based solution developed for the project management purposes may use the core functionalities of the both described solutions:

- continual inspection of the project team's work in order to verify if the specified level of quality is achieved;
- incessant validation the quality of the third-party supplier inputs.

4. **Issue & Change Management with flexible problem-solving.** The Issue and Change management use case is inspired by several blockchain-based solutions for the supply chain area and Horizon state's solution. As was already mentioned before, for the supply chain is essential to track the whole lifecycle of deliveries for in case of deviations to react immediately. The same applies for managing projects, every single issue or change in project plan must be tracked and traced in order to take appropriate actions on time. Horizon state is providing a blockchain-based voting and decision making systems for the Enterprise sector as well as the government sector (Horizon state, 2019). The analogical advantages that can be gained through using Blockchain technology for managing project issues and changes are following:

   - well-timed stakeholder's awareness about the issue or change;
   - involving of all stakeholders into flexible decision-making and problem-solving processes primarily focused on reaching consensus;

5. **Cost management.** The main idea of the identified use case for managing project cost were borrowed from existing innovative blockchain-based payment systems. The useful functionalities of the blockchain-based payment systems that can potentially be valuable for the project management domain are following:
   - digital contracts between business partners and suppliers without third party intermediaries;
   - automatically cost scheduling with the lower level of the cost breakdown structure;
   - improvement of the estimate cost based on real-time tracking of the project cost;
   - prevent project from going over budget after registering issues or changes through smart contract inspections;

6. **Project closing.** Similarly, as quality management and issue and change management use cases the idea of the project closing use case was borrowed from blockchain-based solutions for regulatory compliance and voting and decision making system. The key functionalities of the mentioned blockchain-based solutions can potentially find appropriate utilization within the project closing phase:
   - enforcement confirmation of that agreed project outcomes were being delivered as well as of validation of acceptance of them by customers and sponsors.
   - concluding inspection before project closure targeted to check whether all project tasks are resolved and deliverables are delivered;

- automatically execution of actions included to the project closure report;

7. **Base for lessons learned.** This use case is inspired by successfully applied blockchain-based solutions in insurance industry, Open Insurance Data Link and RiskBlock Alliance. The Open Insurance Data Link "*is the Blockchain platform that enables the efficient, secure and permissioned-based data collection from insurance companies and the analysis of that data back with insurance companies*" (AAIS, 2019). The RiskBlock Alliance is the industry-led consortium represented by 31 risk management and insurance companies that are "*building of an open, secure ecosystem for the insurance industry (*Malvern, 2018*)*. In simple terms the Risk Block is the decentralized collaboration platform developed for easy sharing and managing policies within entire industry. Each joined member of the Risk Block Alliance gains the ability to create proprietary applications that use the industry policies through Blockchain and share the data amongst other consortium's members.
   The creation of the similar solution for the project management area can be beneficial for sharing data related to the project problems, failures, their resolution and best practices. Such solution can be used as a global base for lessons learned for future projects across various industries. By connecting the Blockchain decentralized platform for data sharing with the artificial intelligence there is another option how to make the project management operations smarter and more productive.

8. **Rewarding system.** The idea of the use case proposing innovative rewarding system of the project team members was borrowed from blockchain-based social platforms where the authors are rewarded for their activity at the network, more commonly for sharing content. The special incentivization mechanism works for keeping the users motivated and active within the network. In accordance with the same principles such platform can be established for the project team members, to enable them to collect rewards during the project for their high performance work and excellent results without any central authority meddling.

According to the analysis through the methods of abstraction and analogy the potential use cases of application the Blockchain technology for project management purposes were identified. The further description of each use case is the subject of the following section of this chapter. However, the discovered Blockchain technology use cases still need to be verified by experts from the project management area to be considered as applicable in the analyzed domain. The next sixth thesis chapter *Evaluation of use cases* is dedicated to explanation of the assessment process performed within the third stage of the thesis empirical work.

5.3 Description of the potential use cases

This thesis section deals with the detailed explanation of the 8 identified potential use cases of applying Blockchain technology in project management area. Each use case is sufficiently described in accordance with the following structure:

- Description of the project management problems which are supposed to be resolved by a solution proposed in the use case;

- Description of the project types for which the proposed solution applies;

- Description of the benefits which can be potentially gained through using the proposed solution;

- Description of the proposed solution including utilized Blockchain technology advantages;

5.3.1 1. use case - Scheduling & milestone tracking (supplier inputs included)

Problems to resolve:

- lack of continuous monitoring and tracking of project objectives in real-time,
- insufficient stakeholder awareness.

For what type of projects:

Large projects with a wide scope and complex deliveries. Such projects have hundreds of milestones, inputs and outputs of key suppliers. Therefore, there is a need to continually monitor and control the progress of the project. For example: complex IT projects, manufacturing project.

Benefits of using:

- trusted collaboration platform for better awareness about project progress,
- all project information is kept in records and cannot be changed or lost,
- data can be used for the analysis in Post-Project review.

Solution description:

Trusted Blockchain Network with all participants involved: customers, project lead, project team, sponsors, executives, steering committee, key suppliers and etc. The Blockchain technology records everything in transactions as the historical register of every meaningful indicator, even the development of a project.

Blockchain-powered scheduling and milestone tracking solution enables all involved participants to oversee the project real-time progress in detail. The precise and detailed planned project schedule is shared between all stakeholders. The level of detail can be regulated by roles of the participants by Blockchain's permissions. Blockchain technology does not let any change to a planned schedule, but allows all participants to track in detail the actual project progress in real-time. Transactions related to the project progress are recorded with the actual time-stamp in the moment when it happened. Blockchain Network allows project members to track the start and finish of the project phases, status changes of the important tasks and project milestones in a transparent way. So all project participants have opportunity to be aware of the actual state of the project "up-to the-minute". Each project progress transaction can be completed with the information about delays or

completion ahead of time, that enable to monitor how the project develops in comparison with the planned schedule.

Transactions about the delivery of supplier inputs can be also integrated intoto the main project schedule. Supplier delay can cause delays in project, because the project deliverables often directly depend on the supplier inputs. If this information would be tracked within the main project schedule, it can help not only to take preventative measures in time but also to improve Issue & Change management and Resource allocation management.

5.3.2 2. use case - Requirements management

Problems to resolve:

- poor requirements management,
- unclear specification of requirements,
- overlapping requirements,
- duplicating requirements,
- change of the project scope,
- quickly changing customer requirements,
- unrealistic customer expectations.

For what type of projects:

Large projects which involve integrating a wide scope of products and services into a total solution to meet the customer's complex and unique needs. There is a need for: precise and detail requirement specification, historical traceability of requirements, requirement status tracking, trace requirements relationships. For example: complex IT project targeted to produce a technical device which comprises hardware and software development.

Benefits of using:

- paperless requirements management without endless cycle of rework such as reviews in the form of a document or spreadsheet,
- online approach makes it easier for distributed and virtual cooperation with customer and alongside for project team members as well,
- enabling teams to communicate the appropriate level of project scope in the more efficient way,
- better traceability of the requirements.

Solution description:

Trusted Blockchain Network with all participants involved: customers, project lead, project team, sponsors, executives, steering committee and etc. The Blockchain technology records everything in transactions, that are highly structured, transparent, invariable, safe, verifiable. It can be used for the successful requirements management that exactly requires a highly structured and transparent register of information about customer needs and expectations.

Blockchain-based way how to manage customer requirements lies in transformation of the interaction process between customer and project team. In the initiation stage of the project all accepted customer requirements with detailed specification, relationships and priorities are shared between all stakeholders. All new requirements coming during the project are also distributelly stored as transactions with the same attributes as requirements at the start of the project. New requirements after creation gains automatically status "Proposed". After the acceptation by business analysts and developers the status changed to "Approved" or "Rejected". So that way all incoming requirements are historically traceable and well categorized.

When the requirement gains the status "Approved" it means that the relationships and dependencies had been analysed and already set. The relationships and dependencies between requirements can be implemented with use of Smart Contracts. So change of the one requirement can trigger a chain of changes to other requirements.

5.3.3 3. use case - Quality management

Problems to resolve:

- poor quality control,
- different perceptions about quality,
- absence of the supplier quality assurance requirements,
- inspection over prevention,
- lack of continuous improvement,
- customer dissatisfaction with the quality of project outcomes.

For what type of projects:

Large projects which cooperate with several suppliers. There is a need to check the quality of service, row material alongside with a single product part or finished product. The same applies to project outputs as well. For example: complex projects in technology, automobile, aviation areas etc.

Benefits of using:

- track measurable improvement of the project deliverables,
- contribute to rise customer satisfaction not only with quality of project outputs but with the whole delivery process as well,
- the transparency and specificity of the blockchain-based solution help build trust in the quality of the project outcomes,
- prevention over inspection. It's better to pay cost of conformance than the cost of non-conformance,
- as the evidence of the continual improvement works.

Solution description:

Trusted Blockchain Network with all participants involved: customers, project lead, project team, sponsors, executives, steering committee and key suppliers etc. Blockchain

technology is a distributed decentralized and immutable ledger that makes secure and prolific transactions. With relying on shared data and immutable ledger the project team can prove that agreed quality is being delivered as well as to validate the quality of the supplier inputs.

Blockchain technology-based project quality management is about optimal investment in conformance cost. The main goal is to adjust project processes for making quality control an integral part of everyday activities. With the aid of Blockchain technology it is possible to "set" the project quality level by systematically managing all activities in a way to achieve a specified level of quality. As opposed to traditional projects in which the contrary approach is applied (the quality activities are defined).

By connecting IoT and Blockchain technology it is possible to incessantly validate the quality of the supplier inputs. The same approach can be used for the all project deliverables produced by the project team. It can be realized by measuring project outputs and gathering data prior to pilot testing within Blockchain. Further these results can be compared and analysed in detail to track a measurable improvement of the project outputs. The other possibility is the usage of Smart Contracts which serve as an independent quality gateway for the final project deliverables, which is triggered based on definition of the target state of the project main outputs.

5.3.4 4. use case - Issue & Change Management with flexible problem-solving

Problems to resolve:

- lack of awareness and understanding of issue or change,
- solving different problems in the same way,
- poor communication about resolving the problem,
- insufficient consensus between stakeholders.

For what type of projects:

Large projects interconnected with various elements, with high dependencies to another related projects or another external factors. There is a need to continual monitor project health by identifying and resolving unexpected issues. For example: Huge regional projects, construction projects.

Benefits of using:

- eliminate possible negative impacts on the project,
- reduced risk,
- greater effectiveness by reducing the need to organize meetings and third-party engagement,
- increase flexibility in decision-making by removing bureaucracy and intermediaries;
- higher success rate,
- record issue resolution for future reference and project learning.

Solution description:

Trusted Blockchain Network with all participants involved: customers, project lead, project team, sponsors, executives, steering committee etc. The communication capability of the Blockchain technology enables rapid transfer of information between all participating nodes. At the same time inside Blockchain it's not possible to change the data without it being seen. These Blockchain's advantages can be used for dealing with issue and changes within project management.

The potential of creating issue and change log on Blockchain lies in the awareness of all stakeholders about issues and involving them into flexible problem-solving process. The integration of customers, vendors, project sponsors and project team into the Blockchain Network will make managing issues such as problems or changes easier. The key for successful issue management is well-timed awareness about the problem or change. Within Blockchain network any modification in the project such as component deficiency reports and resource change are currently displayed in each participating node.

Furthermore, within Blockchain Network all participants can be simultaneously required to attend the collective problem-solving for enabling the continuation of the project. It can be performed with the use of Smart Contracts and the blockchain-based approval tool. The problem-solving action can be initiated with dependence to the issue attributes (status, priority, type, deadline etc.). Allowing all parties involved to make an informed decision based on a common set of trusted data.

The Blockchain-based solution for managing issue and changes allows to provide the latest statuses and other data attributes of the issue. All project participants would be always aware about problems and can contribute by participation in collective problem-solving as whether the issue shall be solved or the change shall be executed.

5.3.5 5. use case - Cost Management

Problems to resolve:

- the cost estimate for the entire project is no reliable,
- over budgeting,
- cost accounting, not cost analysis,
- reduced opportunity to decrease the cost during the project delivery process.

For what type of projects:

Large projects for which it is difficult to estimate the cost due to their uniqueness. There is a need to constantly collect, analyse, evaluate and reporting the cost information for budgeting, improving estimates, forecasting and monitoring costs. For example: large project from energy, nuclear energy areas.

Benefits of using:

- distributed, transparent, historical overview of economic transactions,
- real-time cost management,
- improve calculation of the estimation and forecast cost,

- allowing to avoid transaction fees.

Solution description:

Trusted Blockchain Network with all participants involved: customers, project lead, project team, sponsors, executives, steering committee key suppliers etc. Blockchain technology is a new path in transmitting both sensitive data and secure payments with trust and without additional fees. Alongside Blockchain enables to automatically execute business contracts between several business parties as well. All these opportunities can satisfy needs of the Project Cost Management.

Blockchain-based Cost Management solution lies in cost scheduling with the lower levels of the cost breakdown structure (CBS) and implementation of the Smart contract payments. The detailed planned project cost item-by-item supplemented with terms is shared between all stakeholders. Blockchain technology does not let to change planned CBS but allows all participants to track in detail the actual cost usage in real-time. It can be performed by implementing Smart Contracts in each project phase, milestone or scheduled action to handle automatically payments to supplier organizations, subcontractors and project team members. The peer-to-peer database first captures all terms and conditions of the agreed digital contracts, then uses data gleaned across distributed nodes during the project to determine when those conditions have been fulfilled and then the payment is authorized. So that transactions related to the cost usage are recorded with the actual time-stamp in the moment when they were just spent.

Blockchain-based solutions allow to manage costs within the current budget and current forecast by reviewing spent cost items side by side with the planned budget. It provides the clear understanding of what exactly went into the current budget and current forecast. The Blockchain-based solution for the Project Cost management has also an ability to reflect money spent on unexpected issues or changes. It can create a distinct group of cost, that can be tracked separately.

5.3.6 6. use case – Project closing

Problems to resolve:

- never ending project,
- stakeholders do not realize that the project is over and continue treat it as an active project,
- negative perception of project team efforts for matters that are not their fault or responsibility.

For what type of projects:

Large projects with complex workflow and many deliverables. For example: software projects, technology projects.

Benefits of using:

- better auditability of project success or failure,

- help to ensure that all the work has been completed in agreed way, all appropriate project management processes have been executed,
- allow a fromal recognition of the completion of a project—everyone agrees that the project is finished.

Solution description:

Trusted Blockchain Network with all participants involved: customers, project lead, project team, sponsors, executives, steering committee etc. Blockchain technology is a distributed decentralized and immutable ledger that makes secure and trust transactions. With relying on shared data and immutable ledger the project team can prove that agreed deliverables were being delivered as well as to validate the acceptation of them by customers and sponsors.

Blockchain-based Project Closure procedure is about implementation of the Project Closure Report with use of the Smart Contracts. The Project Closure report would contain the list of activities, in this case the list of digital contracts that are targeted to ensure that project closure is completed smoothly and efficiently. Once the Project Closure Report has been approved by the project sponsor, the closure activities stated in the report are actioned. After that, the project may be closed.

Below is a list of closure actions and activities which can be executed automatically with the use of Smart Contracts to check if the exit criteria are met:

- ✓ all issues are resolved,
- ✓ all documents and deliverables are up-to-date,
- ✓ acquisition of confirmation about the delivery and formal acceptance of deliverables by the customer,
- ✓ ensuring that all costs are charged to the project,
- ✓ informing stakeholders of the closure of the project,
- ✓ cancelling supplier contracts,
- ✓ releasing staff and equipment,
- ✓ closing of project accounts.

5.3.7 7. use case - Base for lessons learned

Problems to resolve:

- no effective utilization of lessons learned from past project,
- constantly solving the same problem over and over again.

For what type of projects:

For every project.

Benefits of using:

- allow to record lessons learned as they are learned, not rather than waiting until the end,

- more precise development of project management standards and templates,
- more targeted benchmarking and mentoring.

Solution description:

Trusted Blockchain Network with all participants involved: customers, project lead, project team, sponsors, executives, steering committee etc. Blockchain technology records everything in transactions as the historical register of every meaningful indicator. Distributed storage allows to record and transmit data that are transparent, invisible, secure, controllable, and resistant to outages and hacker attacks and loss.

Blockchain technology serves as a valuable archive for the experience gained and its future analysis, auditing and evaluation purposes. That is what actually needs for storing of the project management intellectual property such as "Lessons Learned" form the past projects. The distributed sharing of information prevents of data lose, unpermissioned changes or deletion. The historical register of the "lessons learned" provides an overview how the resolution of the same problem has been changing over time in order to improve.

5.3.8 8. use case - Rewarding system

Problems to resolve:

- unmotivated team members,
- poor team spirit,
- the team isn't high performing,
- lack of commitment – team members don't commit or buy in to decisions,
- avoidance of accountability – unwilling to discuss performance behaviours,
- negligence of results – not focused on achieving the team's results.

For what type of projects:

Large projects with a several number of virtual and distant teams. For example: complex IT projects.

Benefits of using:

- team oriented on performance and focused on results,
- devoted and motivated individuals.

Solution description:

Trusted Blockchain Network with all participants involved: customers, project lead, project team, sponsors, executives, steering committee etc. Blockchain technology records everything in transactions as the reliable historical register of every meaningful indicator, even the project performance based on the project progress development.

The idea of the blockchain-based rewarding system is in remuneration of the team for the registered great performance on the project. It can be done in two ways: financial way with the aid of cryptotokens and non-financial.

Financial way how to reward: the project team members would have an opportunity to collect cryptotokens during the project for their high performance work and excellent results. Such as tasks completed under budget; deliverables that meet desired quality; participation on problem-solving, extra time etc. By implementation special algorithms with using of Smart Contracts the cryptotokens will be distributed automatically to whole team or to particular team member. Then at the end of the project team members can exchange gained cryptotokens to real money. The exchange rate would depend: on money saved (in case if the project completed under budget) or on the willingness of project sponsors to allocate particular amount to reward project team members.

Non-financial way how to reward: celebration of every meaningful moment of the project, such as the successful end of the project phase, meeting task deadline or milestone. With using Smart Contracts it's possible to automatically send motivated notifications messages with regard to project context when the appropriate conditions would be met.

5.4 Proposed use cases vs. PMBOK Knowledge Areas

Before the evaluation process the preliminary verification of suitability of the 8 proposed use cases with requirements and needs of the project management domain was additionally performed. The preparatory check was executed thorough creation of the traceability matrix that enables to determine whether project management domain is sufficiently covered by the 8 proposed use cases of application Blockchain technology. The verification matrix was created with the use of the 10 PMBOK Knowledge Areas located in table columns and 8 proposed use cases in table rows. Since the PMBOK Knowledge Areas defined by Project management institute represents *"a complete set of concepts, terms, and activities that make up a professional field, project management field, or area of specialization"* (PMI, 2013). The PMBOK Guide comprehensively defines the project management knowledge areas in integration with 5 main project management process groups comprising of 49 project management processes (PMI, 2017). The PMBOK Knowledge Areas also have been globally recognized as a highly useful base for the planning phase of a project and for driving project to success (Zwikael, 2009).

As it can be seen from the Table 13 situated below, each of the 8 proposed use cases fits at least one knowledge area. It doesn't mean that there is no possibility to identify the other potential use cases of applying Blockchain technology in project management domain. The traceability matrix just strictly represents that the proposed use cases don't skip any of the project management areas of knowledge. As well as there is any pointless use case that doesn't meet any of the 10 project management knowledge areas defined by Project Management Institute.

Table 13: Traceability matrix with proposed use cases covered by PMBOK Knowledge Areas (Author; PMI, 2017)

Proposed use cases of application Blockchain technology in project management area	**PMBOK Knowledge Areas**									
	1. Project Integration Management	*2. Project Scope Management*	*3. Project Schedule Management*	*4. Project Cost Management*	*5. Project Quality Management*	*6. Project Resource Management*	*7. Project Communications Management*	*8. Project Risk Management*	*9. Project Procurement Management*	*10. Project Stakeholder Management*
1. Scheduling & milestone tracking(supplier inputs included)	✓		✓				✓		✓	✓
2. Requirements management		✓								✓
3. Quality management					✓				✓	
4. Issue & Change Management with flexible problem-solving							✓	✓		
5. Cost management				✓					✓	
6. Project closing	✓									✓
7. Base for lessons learned	✓				✓					
8. Rewarding system						✓	✓			

6 Evaluation of use cases

As it was already mentioned in the previous section, the identified potential Blockchain use cases should be verified to be considered as applicable and useful in the analyzed domain. The verification was performed within the last third stage of the thesis empirical work through evaluation procedure in order to rigorously proof use cases relevance for practice in the analyzed domain. From the available evaluation methods, the questionnaire survey was chosen as the most suitable form of gathering more accurate evaluation results by addressing it to a group of respondents with required area of expertise and experience.

This thesis chapter deals with the detailed description of the evaluation process performed within this work in order to determine business viability and technical feasibility of the 8 Blockchain use cases proposed for the project management area.

6.1 Survey workflow

The survey was carried out using questionnaires prepared in Google forms and distributed to respondents via an online link. The questionnaire's form is structured into three main parts:

1. *Introductory part*. The introductory part of the questionnaire deals with providing all necessary information about the survey's purposes and workflow. Supporting material about Blockchain technology is provided to aid the respondents during the questionnaire process. In this part of the questionnaire form the respondents are asked about their experience with project management practice and their awareness about Blockchain technology.
2. *Assessment part*. The assessment part is the most extensive part of the questionnaire form since it is devoted to the main purpose of the survey - the evaluation of the 8 proposed uses cases. In this section the questionnaire form requires that the respondents evaluate each use case under a given set of evaluation criteria. The evaluation criteria are the same for all use cases and are presented by 9 rating scale questions and 2 dichotomous questions. In this part of the questionnaire form respondents are optionally asked to provide feedback regarding each of the proposed use cases.
3. *Concluding part*. The concluding part of the questionnaire is about respondent's suggestions and expectations. In this part of the questionnaire the respondents may optionally propose any other potential options of using Blockchain technology in the project management domain. The last two questions of the concluding part of the form ask respondents about their estimates of when in the near future the Blockchain technology will be applied in the analysed area.

To facilitate the survey process for respondents and the survey executor, the questionnaire form was sent to the respondents through an online link. The respondents were able to complete the questionnaire anonymously in any moment of a given period of time. For the

survey executor the only approach of performing the questionnaire survey was practically effective with respect to gathering respondent's responses to all obligatory questions in the same format. The empty questionnaire form that was distributed to respondents and is attached in the Appendix to this thesis. The questionnaire forms competed by survey's participants are also attached to this diploma thesis as a digital attachment.

After obtaining a sufficient number of responses needed to get a reliable data sample the gathered results were processed and further analysed. The following sections of the sixth chapter deal with the presentation and interpretation of the obtained results divided by the three survey's dimensions such as respondents, evaluation of the use cases, predictions for Blockchain technology's future in the project management area.

6.2 Respondents statistics

The survey realized within this diploma thesis was focused to primarily reach out to experts from the project management area in order to gain relevant insights about the applicability of the proposed use cases. With regard to the questionnaire's purpose and its extent the survey does not necessarily require a large number of participants. Therefore, the obtained opinions from at least 4 project management experts was considered as a sufficient sample for the evaluation purposes. Statics regarding the participating respondents is shown below.

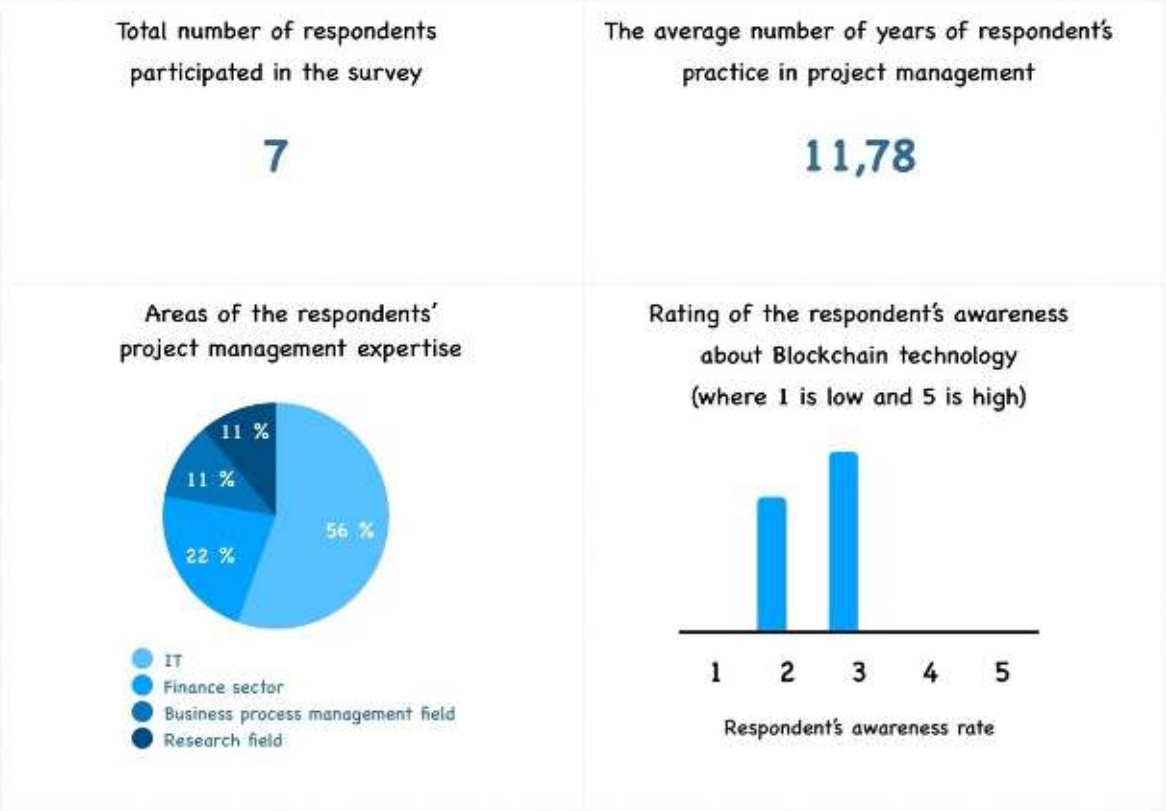

Figure 16: Respondents' statistics (Author)

As it can be seen from the statistics presented above, the respondents which participated in the thesis questionnaire survey are experienced enough in the project management field. From all 7 respondents only one project manager has 1,5 years of practice, the other 5 have more than 5 years. The most experienced project manager has 30 years of practice. The 5 survey's participants have practice with managing IT projects. The other areas of expertise are stranded by individuals that have management practice in only one area or in two areas at once. 2 survey participants are experienced with managing IT projects as well as Banking industry's projects and Business process management. The average rate of the respondent's awareness about Blockchain technology can be considered as medium, since 3 of 7 respondents rated their awareness as somewhat low and the other 4 project management experts rated it as medium.

6.3 Evaluation results

The main focus of the thesis questionnaire survey was the evaluation of the 8 proposed use cases. For the purposes of the performed assessment a specific set of 9 evaluation criteria was defined to enable to rigorously prove the relevance of use cases for their practical application in the project management domain. The definition of the used evaluation criteria is focused on rating of the business viability, functional utilization of the Blockchain technology advantages and several technical aspects of the proposed solutions. As part of the evaluation section of the questionnaire form the respondents were required to rate the proposed use cases under a specific set of evaluation criteria with the aid of the rating scale of 1 to 5 where:

1 - low,
2 - somewhat low,
3 - medium,
4 - somewhat high,
5 – high.

The entire list of the applied evaluation criteria together with the processed evaluation results are included to the Table 14 located below. As it can be seen from the table rows the evaluation results are presented by average rating values calculated for the 9 criteria. The total rating for each proposed use case was calculated by summarizing all criteria values, since from the formulation of almost all criteria follows that the higher rating the more relevant and useful the solution is. The only one exception is the sixth criterion characterizing the operational complexity, exactly data amount, amount and complexity of relationships, complexity of user behavior inside the system. However, it can be considered separately together with the analysis of the use cases total ratings. Based on the total ratings and solution complexity considerations the Top 3 most relevant and applicable use cases of using Blockchain technology in the project management domain were identified:

1. Cost management,
2. Requirements management,
3. Quality management.

Table 14: Evaluation results (Author)

Use cases / Evaluation criteria	**1. Scheduling and milestone tracking**	**2. Requirements management**	**3. Quality management**	**4. Issue & Change Management**	**5. Cost management**	**6. Project closing**	**7. Base for lessons learned**	**8. Rewarding system**
1. Suitability of the use case for Blockchain technology application	*2,57*	*3,14*	*3*	*3*	*3,29*	*2,29*	*2,14*	*2,29*
2. Problem resolution arising from using Blockchain technology described within the use case	*2,43*	*2,57*	*2,71*	*2,43*	*2,86*	*2,14*	*2,29*	*1,86*
3. Utilisation of Blockchain technology advantages within the use case	*2,71*	*3,29*	*3*	*2,29*	*3,14*	*1,71*	*2,14*	*2,29*
4. Business viability of the use case from the Project management perspective	*2,29*	*3,14*	*3,14*	*2*	*3*	*1,71*	*1,86*	*2,14*
5. Technical feasibility of the use case from the solution development perspective	*3*	*2,86*	*2,29*	*3*	*3,29*	*2,71*	*2,14*	*2,29*
6. Operational complexity of the use case	*3,43*	*3*	*3,14*	*3,14*	*2,57*	*2,71*	*2,14*	*2,29*
7. Comparative advantage of the use case in comparison with the currently offered project management solutions	*2*	*2,43*	*2,86*	*1,86*	*2,43*	*2,29*	*1,86*	*2,14*
8. Disruptive difference in approach of the use case compared to currently offered project management solutions	*2,14*	*2,14*	*2,14*	*1,86*	*2,43*	*1,57*	*2*	*3*
9. Impact of the innovative way of doing things differently proposed in the use case on the Project management domain	*2,43*	*2,14*	*2,43*	*1,71*	*2,86*	*1,57*	*2,14*	*2,71*
Total rating	**23**	**24,71**	**24,71**	**21,29**	**25,86**	**18,71**	**18,71**	**21**

As was prior mentioned in *Approach and methods* the most suitable use case will be conceptually developed in the final solution design part of the thesis work based on evaluation results. The findings from Table 14 indicate that the use case for managing project costs was acknowledged by project management experts as the more relevant and useful from the all 8 proposed use cases. Therefore, the next thesis chapter named *Blockchain-based project management software tool* deals with the solution design especially for Project Cost Management.

6.3.1 Additional use cases' statistics

Together with the rating scale questions the evaluation part of the questionnaire form consists of two additional dichotomous questions. Two charts located below represent the summary statistics of respondents' responses to these two questions.

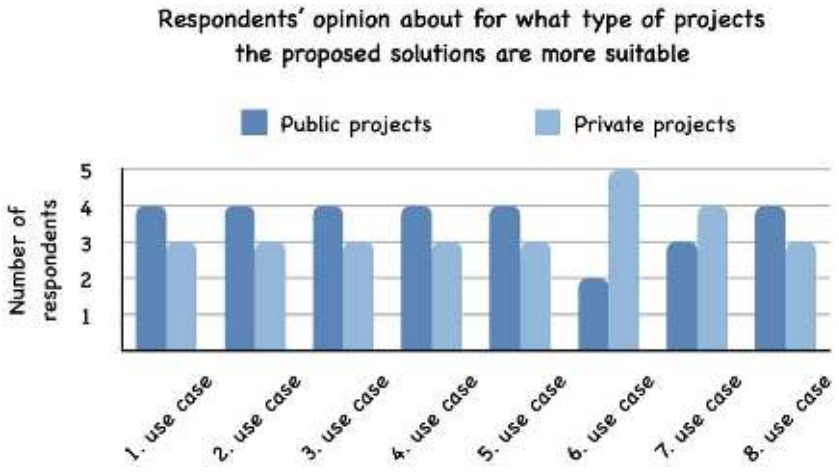

Figure 17: Use cases statistics by project types (Author)

The Figure 17 represents a summary of the responses regarding the question asked from participating respondents in thesis survey about for what type of projects the proposed solutions are most suitable: for public or private. As it can bee seen from the graph representing the results in most cases the respondents can imagine the implementation of such solutions for both public and private projects. The only exception are Project closing and Base for lessons learned. There was a broad convergence of respondents' views that the implementation of such solutions is more appropriate for managing projects on a private basis. However, based on the summary of all responses to this question the public type of projects can be considered as more suitable for the implementation of the blockchain-based solutions for managing projects in general.

The Figure 18 describes the summary statistics of the respondents' responses to the second question that is targeted at determining of respondents' personal interest of such solutions to apply for the management of at least one of their projects. As the graph located above demonstrates, the overwhelming majority of respondents in all 8 cases do not find the proposed solution interesting and useful for applying to at least on one of their projects.

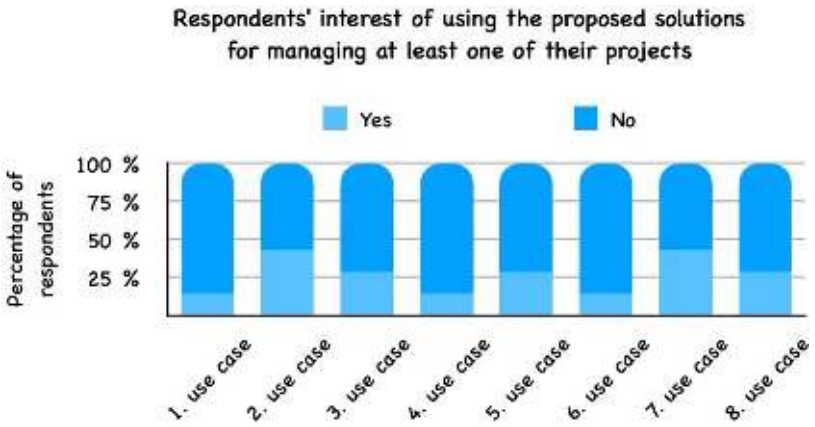

Figure 18: Use cases statistics by respondents' interest (Author)

6.4 Respondents' view about Blockchain's future in project management

Together with the use cases evaluation the respondents were also asked about their estimates regarding Blockchain technology adoption in project management domain. Below there are two charts representing the future of the Blockchain technology adoption in the project management domain created based on the summary of the respondents' estimates.

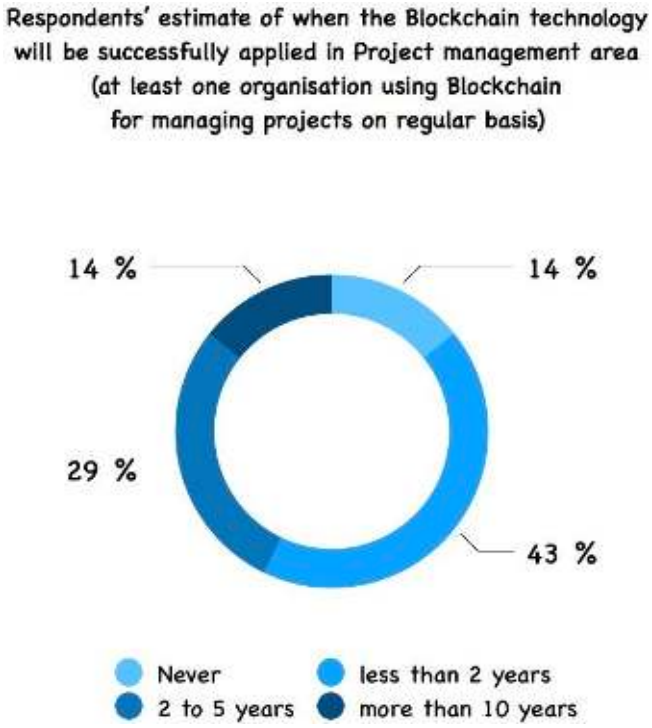

Figure 19: Respondents estimate for the first successfully adopted blockhain-based solution in project management area (Author)

The first chart presents how the respondents estimated when the first blockchain-based solution for managing projects will be successfully adopted at least by one organisation. As it can be seen from the Figure 19 the majority of the respondents guessed that the first

successful implementation of Blockchain technology for managing projects is most likely to appear in less than 2 to 5 years.

The second question asked the respondents about their estimate of when the Blockchain technology will become commonly applied in project management domain. Statistics for the second question is presented by Figure 20Figure 20 located below. There most respondents agreed on that the Blockchain technology will be applied as a standard project management solution in 5 to 10 years.

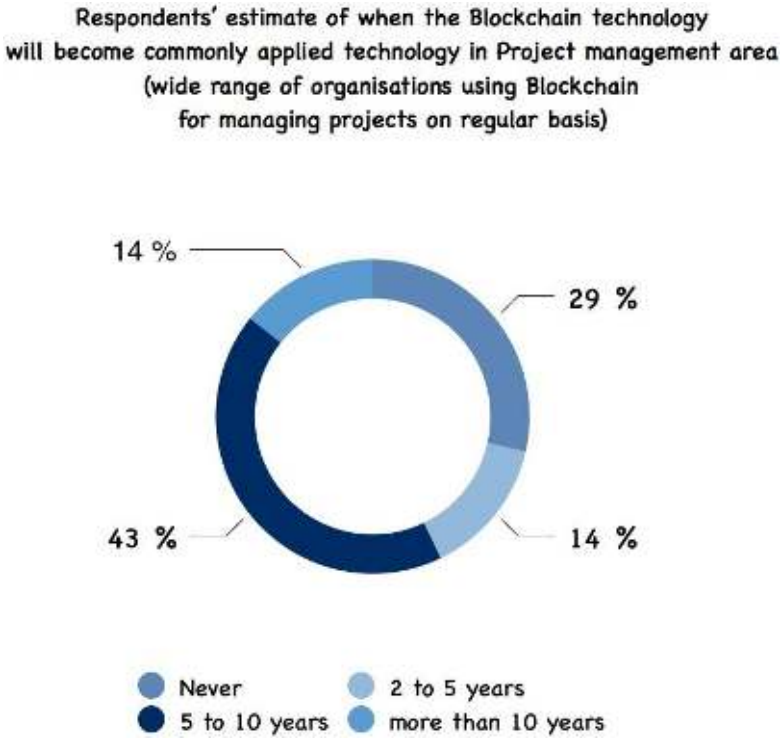

Figure 20: The second prediction for the Blockchain technology future in project management (Author)

7 Blockchain-based project management software tool

In the solution design part of the thesis the proposed Blockchain use cases were evaluated by project management experts in order to choose the more viable and technically feasible one for the solution design part of the thesis. Based on the evaluation performed within the third stage of the thesis empirical research on the proposed use case for Project Cost Management was acknowledged as the most relevant from the overall 8 suggested use cases. Therefore, the main focus of this chapter is the development of the blockchain-based solution for the Project Cost Management. The author of the thesis decided to carry out the solution design under the conditions permitted by the Blockchain network since the project budget and agreed price for the supplier services are such sensitive data required to be protected from public disclosure. The distributed ledger technologies, permissioned Blockchain, better fits the existing requirements for restricted permissions and specification of the privacy levels within the project management solution. However, the participating project management experts of this thesis survey can imagine such a solution to exist for both types of projects, private as well as public.

Within this thesis chapter the solution design is realized through a conceptual implementation with the aid of UML diagrams representing the fundamental layers of the blockchain-based solution. The definition of the main Blockchain application layers was taken from the book "Beginning blockchain: a beginner's guide to building blockchain solutions" published in 2018. The authors of this book gave their own formulation of the fundamental Blockchain layers since so far the "*globally agreed standards segregating the Blockchain components into distinct layers*" haven't been developed yet (Singhal et al., 2018, p.18). Singhal, Dhameja and Panda give the following high-level layered representation of the Blockchain solution in their book (Singhal et al., 2018, p.18):

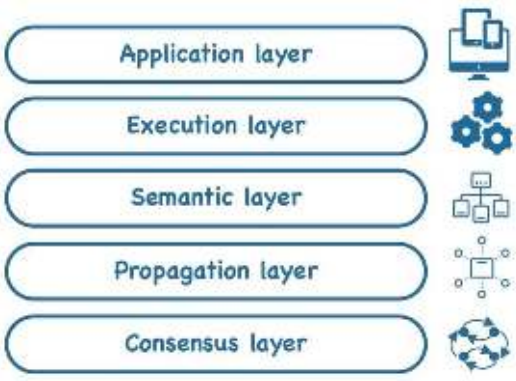

Figure 21: Blockchain solution layers (Singhal et al., 2018, p.18)

The following sections of this chapter present the particular UML models that characterize: execution layer, semantic layer, consensus layer and propagation layer. The application layer is out of scope of this work since it is more about user interface and experience and is

not significantly dependent on the functionality given by the application of the Blockchain technology. Furthermore, it may also differ in context of specific requirements of the individuals or particular organizations. Visual Paradigm online tool was used to assist with diagram visualization of the 4 essential layers of the blockchain-based application for Project Cost Management.

7.1 Execution layer

In general, the execution layer of the Blockchain application mainly presents the functional capabilities of the solution. More precisely the execution layer defines the solution's functionality through specific commands which can be undertaken by end-users through the application interface of the system. As commands can be considered as simple instructions or a set of multiple instructions in the form of smart contracts (Singhal et al., 2018, p. 20). Together with the solution's functionality the execution layer is in charge of the validation of the correct execution of the transactions. Within the execution layer all nodes participating in the Blockchain network execute the commands independently (Singhal et al., 2018, p. 20). The same set of inputs and conditions should always produce the same output on all the Blockchain network nodes, it's essential for avoiding inconsistencies inside the system (Singhal et al., 2018, p. 20).

The **Use Case diagram** was chosen to represent the execution layer of the blockchain-based solution for Project Cost Management. Because this type of the behavioral UML diagram allows to provide a high-level representation of the solution's core functionalities, actors interacting within the system and relationships between them.

The Figure 22 below is a conceptual visualization of the Execution layer with the aid of the UML Use Case diagram. As the diagram shows the solution's core functionalities and incentivization mechanism involvement are included into packages which present the main solution's parts. As can be also seen from the diagram the involvement of the incentivization mechanism is always required during data storing processes when the blocks must be validated and chained. It is happened in the following solution's parts: Budget planning, Task management and Project consumption. The Project Cost control operates based on the data that have been already stored into the system, so it does not need the involvement of the incentivization mechanism. However, the Project Cost control part is restricted under specific permissions as well as the other system parts. The system actors representing the parties involved into Project Cost Management process are placed at the left and right sides of the diagram. The Project team member and supplier are considered as simple users which only produce and validate transactions and block without the right of block creation. The Project manager, Project sponsor and Client are the super users which can also produce transactions with authorization of block creation. The validation and block chaining processes are further described as a part of the applied incentivization algorithm in the next section devoted to *Consensus layer*.

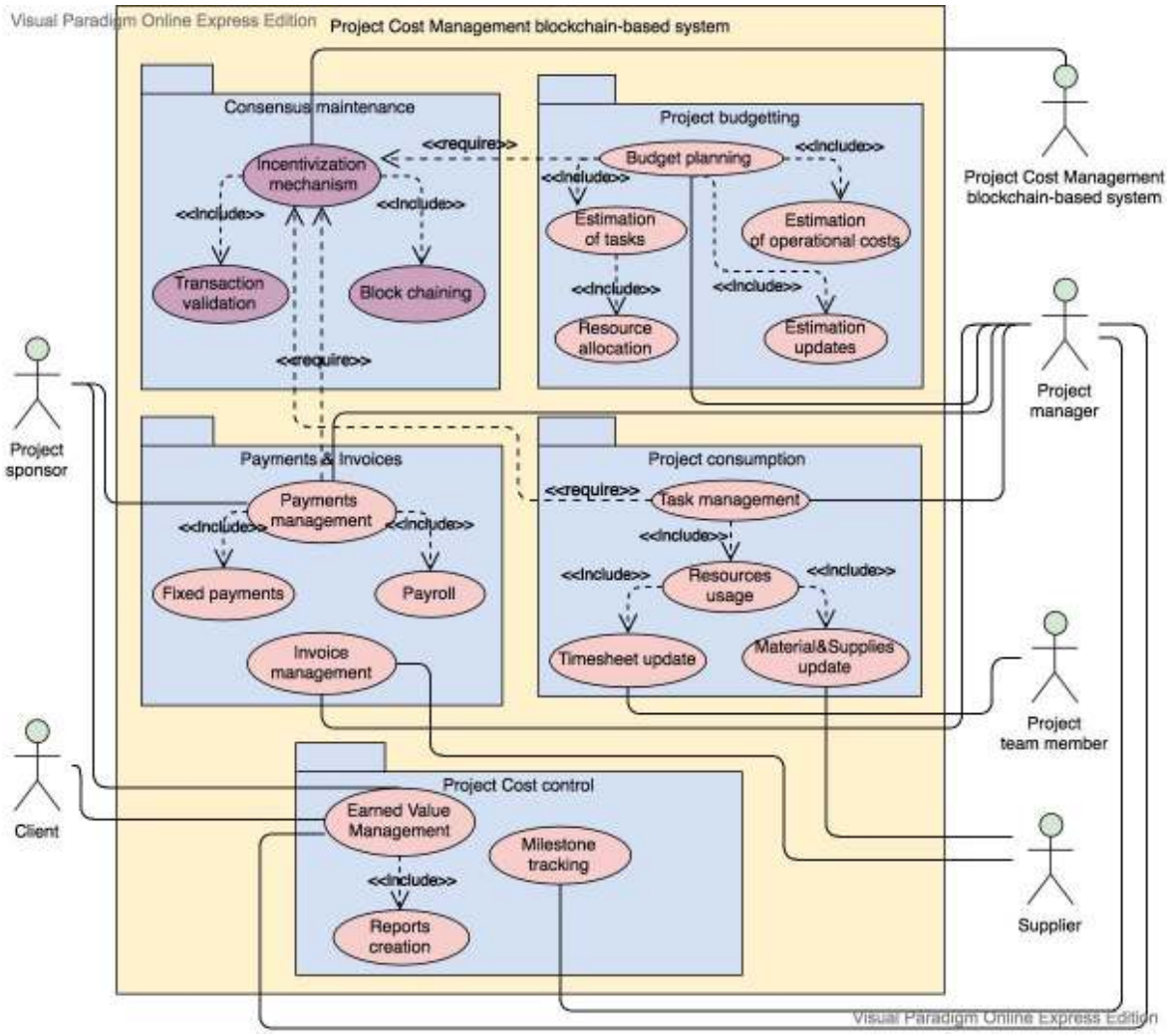

Figure 22: Use case diagram for the Project Cost Management blockchain-based solution (Author)

7.2 Semantic layer

A semantic layer of the Blockchain application is mainly a structural representation of the data used within system. The purpose of the semantic layer is to standardize the definition of the system's data, their orderliness, relationships and dependencies between them (Singhal et al., 2018, p. 20).

The **Class diagram** was considered as the most appropriate form of the semantic layer illustration as it allows to map complex data into familiar terms such as classes, alongside with their attributes describing their basic characteristics and behaviours defined through operations.

The Class diagram of the semantic layer for the Project Cost Management blockchain-based solution is presented by Figure 23 located below.

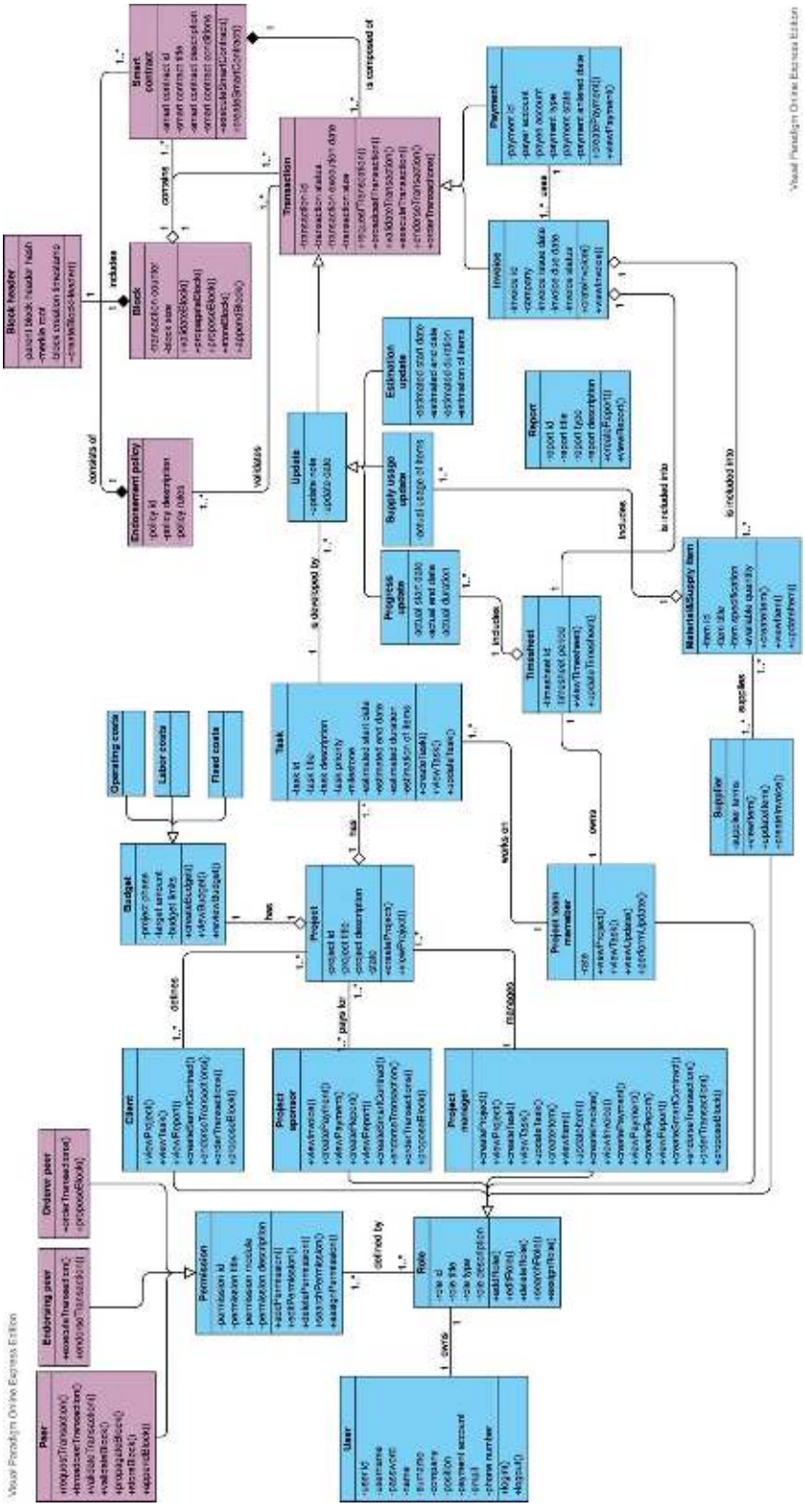

Figure 23: Class diagram for Project Cost Management blockchain-based solution (Author)

As can be seen from the illustration the diagram consists of the main system's objects, users and its key characteristics with the aid of classes and attributes included into them. The arrows between classes represents the dependencies and relationships interconnecting together the system's objects and actors. Alongside with attributes the classes also contain the list of operations which the particular system object or actor is able to perform within

the system. The defined operations represent solution's functionalities and user responsibilities which were already introduced in the previous section with the aid of Use Case diagram. However, the Class diagram also represent the additional user's activities taking place at the solution's back-end and specific for Blockchain-based solution, such as: send transaction request, validate transaction, validate block, append block etc. The Project management, Client and Project Sponsors have some additional back-end activities because they are considered as the peers with the specific responsibilities for the consensus maintenance.

As the diagram shows some classes are colored in violet, such as Transaction, Block, Endorsement policy and etc. These system's objects indicate the main technological difference of the solution developed on the basis of the Blockchain technology against existing traditional solutions:

1. data is structured in form of transactions,
2. transactions are endorsed, ordered, validated and then added into blocks,
3. blocks are chained together.

In context of the provided Class diagram, a project is carried out through following types of task updates:

- resource usage updates (human resources and material) applied for tracking of the project progress and performance as a part of Earned Value Management,
- estimation updates used for improving of the project cost estimation model as a part of a budget review.

The described task updates are executed through transactions inside the blockchain-based Project Cost Management solution. Precisely, the task updates are transaction which are differentiated by their types. The invoices and payments are also standed by other two transaction types which are partly derived from the task updates in following way:

- the invoices can be created on the basis of the resource usage task updates,
- the payment can be entered on the basis of the issued invoices.

By storing data structured as transactions the blockchain-based Project Cost Management solution allows to track a project progress and performance in real time as well as in chronological manner. The advantage that Blockchain Technology within proposed Project Cost Management solution is secure and reliable processing of payments without intermediaries.

7.3 Consensus layer

The consensus layer is the characterizing layer for blockchain-based solutions. "*The primary purpose of this layer is to get all nodes to agree on one consistent state of the ledger*" (Singhal et al., 2018, p. 22). The safety and security of the blockchain-based application is ensured within this layer through a specific incentivization mechanism enforcing consensus. As was previously explained in the *Blockchain algorithm* section of

this diploma thesis, the incentivization algorithm defines the rules for block validation and storing into a distributed ledger which must be respected by all Blockchain network participants in order to maintain consensus within the system.

For the purpose of incentivization algorithm illustration needed for achieving consensus among all Blockchain network nodes the **Sequence diagram** was selected as the most appropriate. Because this type of UML diagrams enables the description of the order of interactions in chronological manner happening between actors and objects inside the system.

Analysing existing consensus algorithms, especially which were successfully applied by several permissioned Blockchain networks today, the author of the thesis decided that the voting-based type of consensus algorithms is more suitable for incentivization mechanism implementation for the proposed Project Cost Management solution. Since the voting-based consensus algorithms apart from the proof-based:

- do not require initiation of any mining completion,
- there is not a necessity to reward miners for work performed,
- do not consume large amounts of processing power and memory.

Afterwards, during detailed study of the existing voting-based consensus algorithms the author of the thesis found out that a **Byzantine Fault Tolerance (BFT)** consensus algorithm lays in the basis of the majority of existing voting-based consensus algorithms (Nguyen and Kim, 2018, p. 123). Therefore, the author came to decision to apply the BFT consensus mechanism for conceptual implementation of the proposed Project Cost Management solution. The several improvement versions of the original Byzantine Fault of Tolerance consensus mechanisms has been created and successfully implemented by modern distributed computer systems including several permissioned Blockchain platforms, such as Hyperledger platforms. "*Hyperledger is a multi-project open source collaborative effort hosted by The Linux Foundation, created to advance cross-industry Blockchain technologies*" (Hyperledger, 2019a). The Hyperledger consortium offers 12 open-source projects which anyone can freely use for establishment their own permissioned Blockchain Network (Hyperledger, 2019a). Considering all available Hyperledger's platforms the author of the thesis decided to use Hyperledger Fabric as a framework for conceptual development of the proposed Project Cost Management blockchain-based solution. In the author's opinion the Hyperledger Fabric is the one of the existing options which suits best to requirements of the the permissioned Blockchain Network. Because it serves as "*a foundation for developing solutions with a modular architecture which allows components such as consensus and membership services to be plug-and-play*" (Hyperledger, 2019b). Therefore, the design of the consensus layer and propagation layer are performed in accordance with the Hyperledger Fabric framework.

The Sequence diagram describing the Consensus layer of the proposed Project Cost Management blockchain-based solution is available from the Figure 24 located above.

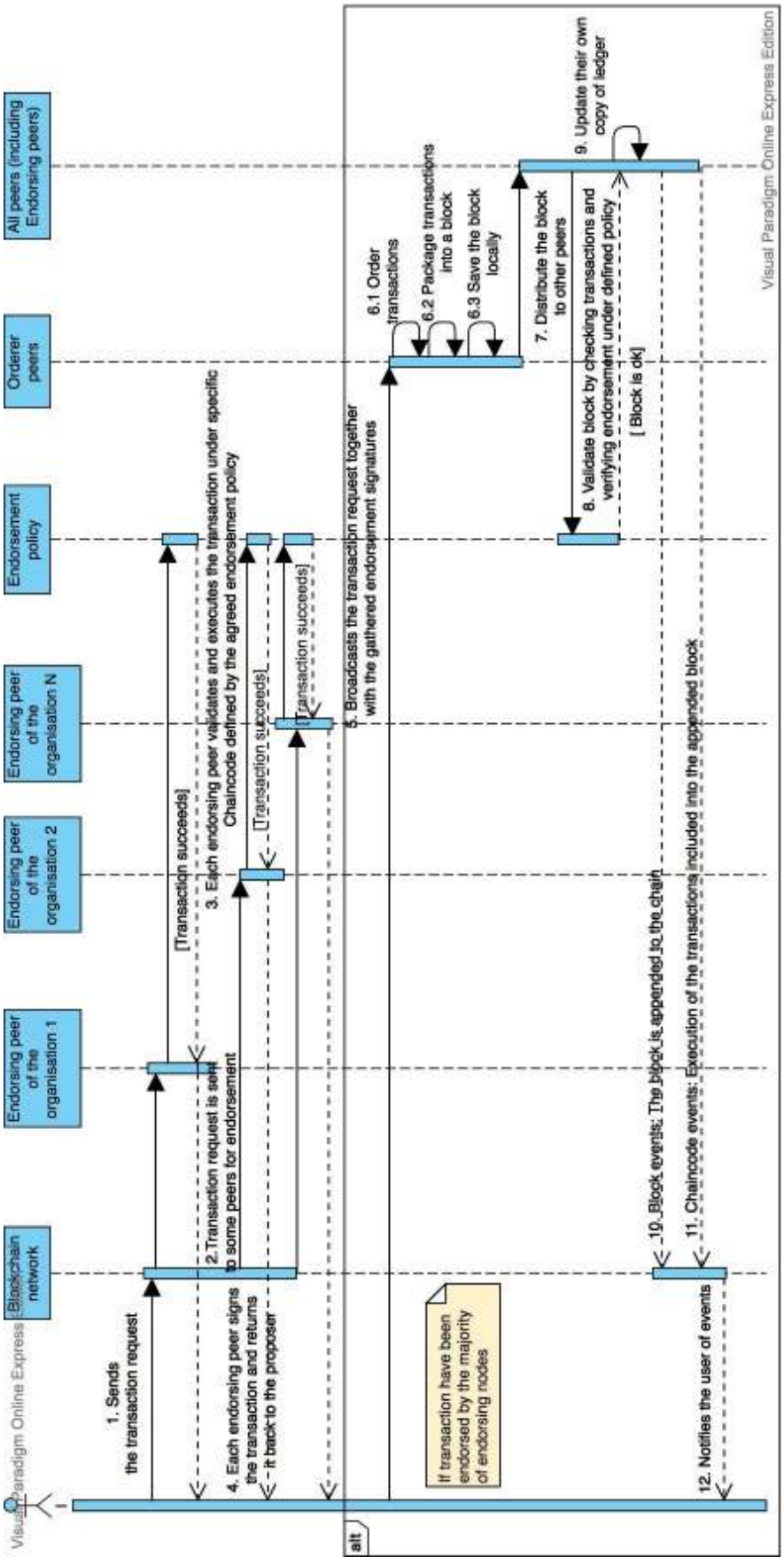

Figure 24: Sequence diagram for the Project Cost Management blockchain-based solution (adapted from Hyperledger, 2017)

As already indicated above, the presented Sequence diagram visualising the Consensus layer of the proposed solution is designed on the basis of the main BFT consensus algorithm principles and in accordance with the Hyperledger Fabric's framework. The Hyperledger Fabric uses improved version of the BFT, where the consensus is entirely reached through the following three main phases:

1. Endorsement of transactions,
2. Ordering transactions,
3. Validation of the block and transactions.

The Sequence diagram demonstrates these main three phases of the improved BFT consensus algorithm in more detailed manner. Below there is a detail explanation of each step presented within the Figure 24:

1. The user through application peer sends the transaction request to the permissioned Blockchain Network.
   - In context of the proposed Project Cost Management blockchain-based solution the transaction request can be initiated through task update or creation of invoices or payments.

2. First, the transaction is sent to endorsing peers for approval (Hyperledger, 2017).

   - In case of the proposed Project Cost Management solution the transaction is handed over to the Project Manager, Client and Project Sponsors which are authorized to approve transactions.

3. Each endorsing peer validates correctness of the transaction through execution of specific smart contracts defined by endorsement policy for simulating the transaction outputs (Hyperledger Fabric, 2019). It is important to notice that the Hyperledger Fabric platform allows to specify different endorsement policies for every transaction type (Rilee, 2018).

4. If the transaction succeeds under policy's conditions and the transaction's output satisfies approving authority, the endorsing peer endorses the transaction by signing it and returns it back to the application peer (Hyperledger, 2017).

5. Once the application peer receives sufficient number of approvals from endorsing peers, it broadcasts the transaction together with endorsing signatures to the Ordering service. The Orderer peers work together to collectively deliver the ordering service in accordance with the Hyperledger Fabric's BFT consensus algorithm.

   - In context of the Project Cost management solution the Project Manager's, Client's and Project Sponsor's nodes are permitted to perform the transaction ordering service.

6. When the number of transactions reaches an agreed threshold called block size or after an agreed time-interval (it depends on configuration policy) the Orderer put transactions in specific order by their creation time and group them into a single block (Hyperledger Fabric, 2019).

7. Once transactions are put into a strict order and packaged into a block, the Orderer peer distributes the created block to other peers (endorsing peer and ordinary peers).

   - In case of the proposed Project Cost Management solution, as the ordinary peers are considered project team members' nodes and nodes belonged to the suppliers' organizations.

8. The peers after receiving the block from Orderer peers validate it by checking correctness of the transactions and verifying endorsement signatures (Hyperledger, 2017).

9. If the distributed block passes the validation procedure, the peer stores it locally by updating its own copy of the ledger (Hyperledger Fabric, 2019).

10. Afterwards, the peer generates appropriate events initiated through specific smart contracts, such as block event and chaincode event. The result of the block event is that the proposed block is chained. (Hyperledger Fabric, 2019).

11. The chaincode event sequentially executes the transactions included into the appended block (Hyperledger Fabric, 2019).

12. As a result, the user is notified through application about the event.

7.4 Propagation layer

The major purpose of the propagation layer of the Blockchain application is to ensure a P2P communication between participating nodes inside the Blockchain network. The propagation layer is in charge of allowing network's nodes to discover each other, to communicate and mutually synchronize with respect to the current state of the distributed ledger (Singhal et al., 2018, p. 21). The propagation layer represents a Blockchain network structure together with all necessary communication activities between the main participating nodes.

The **Deployment diagram** was chosen as the most appropriate type of UML diagrams for propagation layer representation. As this type of UML diagram allows to visualise how the software employ hardware components and relationship between them.

As was referred in previous section devoted to the *Consensus layer*, the Blockchain platform Hyperledger Fabric is considered as the one of suitable options for implementation of the Project Cost Management blockchain-based solution. For that reasons, the visualization of

the propagation layer is directly inspired by the Hyperledger Fabric's Blockchain Network architecture. The several schemes were used as a pattern for creation of two Deployment diagrams of the suggested Project Cost Management blockchain-based tool.

The first diagram located below represents the permissioned Blockchain network which can be established between participating organizations without regard to network's purpose. As the Deployment diagram rather demonstrate the solution infrastructure than its specific functionalities. Therefore, the provided illustration of the propagation layer can be used for conceptual modelling of other permissioned blockchain-based solutions.

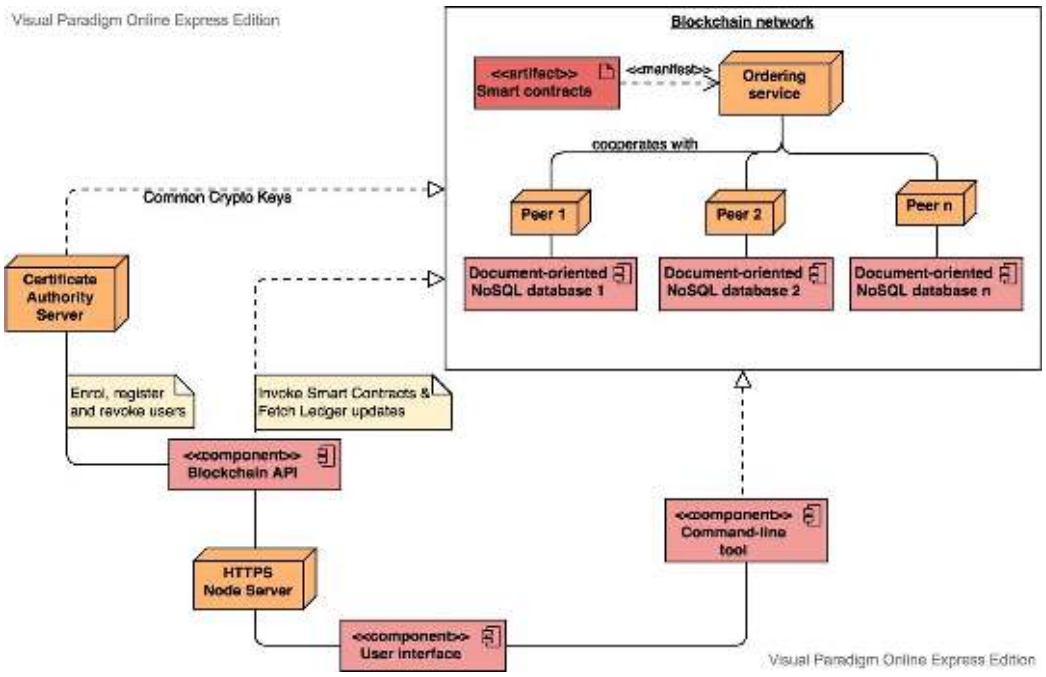

Figure 25: The first Deployment diagram for the Project Cost Management Blockchain-based solution (adapted from Wahab, 2018)

The main goal of Figure 25 is a abstract demonstration of the way how users access the permissioned Blockchain network, which network's components are in charge and through what channels the network's objects communicate with each other within the network.

The second Deployment diagram is presented by Figure 26 which is the more detailed visualization of the permissioned Blockchain network. As can be seen from the Figure 26 the permissioned Blockchain network consists of the 5 main units:

- **Organization unit** describes essential software and hardware components used by each participating organization in order to establish a multi-organization permissioned Blockchain network.
- **Ordering Service unit** is a part of the Consensus Service since it implies the correct order of the transactions and group them into a single block under conditions of the BFT consensus algorithm and agreed configuration policies (Hyperledger, 2017).
- **Consensus Service unit** provides a generalized view on part of the permissioned Blockchain network architecture responsible for running of the applied incentivization mechanism.

- **Network unit** describes the fundamental basis of the permissioned Blockchain network which ensures the entire communication between all 5 main network's units as well as between its components.

For the sake of better readability of the provided two Deployment diagrams, there is an accurate explanation of the presented permissioned Blockchain network's components:

- **Peer** presents a particular computer system that is included into permissioned Blockchain network. In context of the provided Deployment diagrams the peer means a node which belongs to one of the participating organizations.
- **Document-oriented NoSQL database** is a data storage of the particular peer.
- **Persistent Volume Claims (PVC)** is an API which allows users to consume abstract storage resources inside the Blockchain network's cluster (Kubernetes, 2019).
- **Certificate Authority Server** creates and stores asymmetric key pairs for encrypting or decrypting as well as signing or validating. The member management service is implemented through the Certificate Authority Server.
- **Command-line tool (CLI)** is a command language interpreter that allows users to issue commands to the system in the form of successive lines of text (Wikipedia, 2019).
- **Network File system (NFS)** is a shared storage of the configuration files for network's nodes, such as Peers, Endorsers and Orderers (Zhang and Chen, 2017).
- **Orderer** is a peer which is in charge of the block creation and delivery of the proposed block to the other peers inside the permissioned Blockchain network. The Orderer peer is responsible for consistent state of the ledger since it guarantees a correct order of transactions included into each block. As can be noticed the total number of Orderers is different from the number of the participating organizations since in case of the proposed Project Cost Management solution the supplier organizations are considered as ordinary peers without right of the block creation.
- **Stream-processing software platform** presents a public consensus service operating the system's incentivization mechanism. The applied BFT consensus algorithm together with the entire consensus process is explained in detail in the section reserved to *Consensus layer*.
- **Distributed configuration & synchronization services** is a centralized server which allows "*a hierarchical key-value store, distributed configuration service, synchronization service and naming registry for large distributed systems*" (McDonald and Ribeiro, 2016).
- **Container orchestration system** presents a dominant platform needed to automate the "*deployment, scaling, and other management of containerized applications*" within the network's cluster (Kubernetes, 2019).

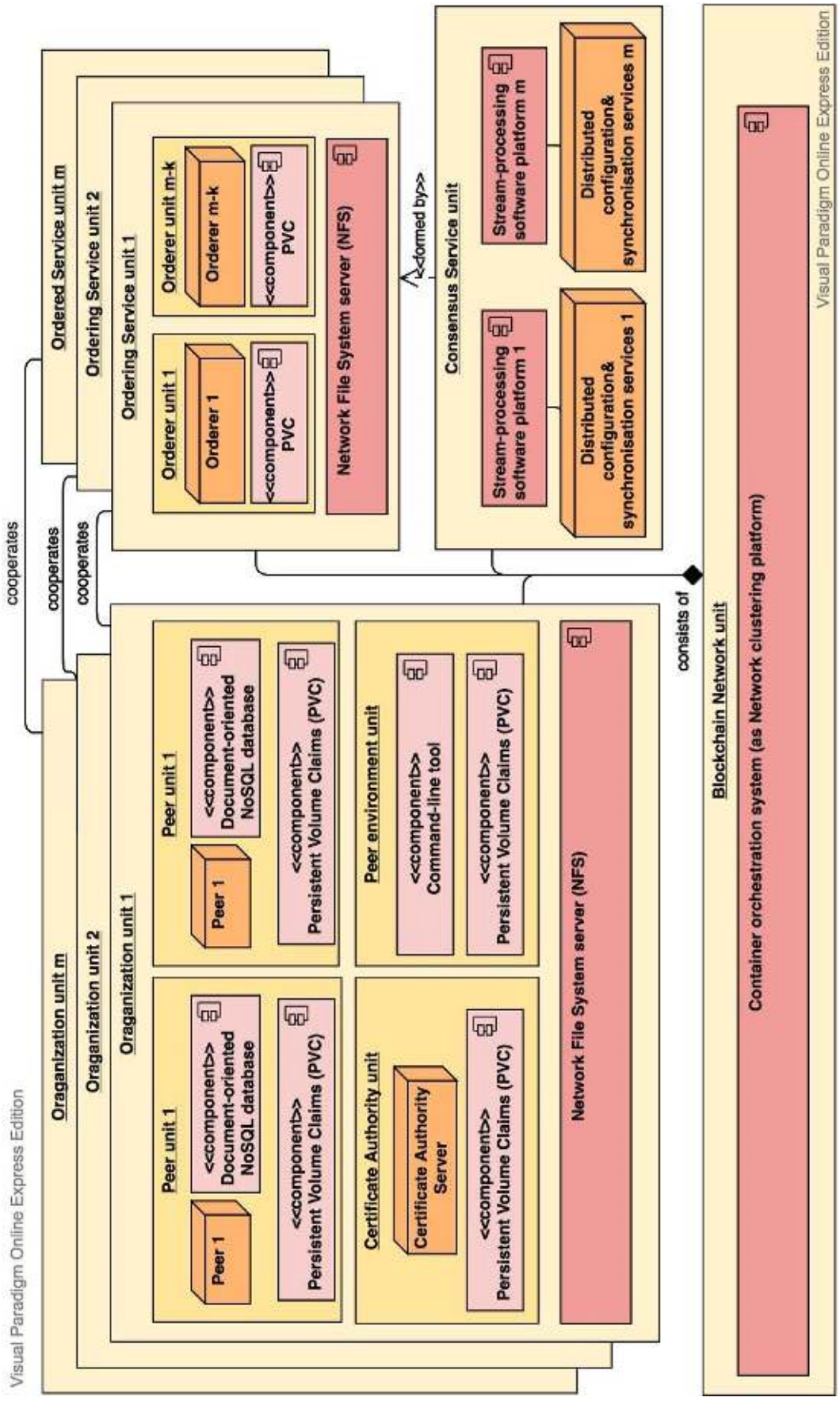

Figure 26: The second Deployment diagram for the Project Cost Management blockchain-based solution (adapted from Zhang and Chen, 2017)

8 Discussion

In order to achieve the main thesis goal appropriately the thesis methodology was accurately defined prior to its realization. The second chapter *Approach and methods* deals with the description of all necessary methods and procedures as well as with an explanation of their systematic sequence. In accordance with the defined thesis methodology the complex and comprehensive empirical work was performed and its workflow was further described in the practical part consisting of 4. - 8. thesis chapters. The main focus of the *Discussion* chapter is to provide a retrospective analysis of key observations and findings gained during the performance of the practical part of the thesis and alongside with the discussion of the thesis limitations and contributions.

In order to review the main thesis outputs in the structural manner the *Discussion* chapter is divided into 3 following parts examining the thesis observations and findings, limitations as well as contributions in a separate manner.

8.1 Thesis key observations and findings

The goal of this section is to present the several observations and findings which were assumed during the carrying out of the questionnaire survey as well as in the process of the finalization of the survey's results. This thesis section is broken down into 3 sub-sections in accordance with the main survey dimensions.

8.1.1 Survey's respondents

As was previously mentioned, the questionnaire survey performed as part of this thesis was focused on primarily reaching out experts from the project management area in order to gather relevant insights about the applicability of the proposed use cases. The project management experts were contacted through different channels: personally through email, personally through LinkedIN and with the help of reliable third parties. Although from the beginning a large participation was not required for the prepared questionnaire, the survey's response rate was lower than previously expected. The survey's response rate is broken down into the following facts:

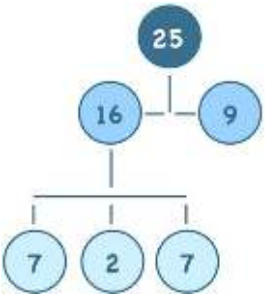

Figure 27: Survey's response rate (Author)

— 25 project management experts in total were asked about their willingness to participate in the questionnaire survey.
— 16 people reacted positively and were provided with the access link to the questionnaire form. The remaining 9 people did not respond on the invitation message.
— 7 project management experts completed questionnaire in a specified period of time.
— 2 people refused to participate in the survey after accessing the link for the reason of the questionnaire's large extent.
— 7 people from the 16 positively reacted did not complete the questionnaire for some personal reasons.

Based on the facts presented above the response rate is 28% which can be considered as relatively low. However, this did not affect the process and reliability of the questionnaire survey performed as part of this thesis. This observation just indicates that it is relatively difficult to gather together a sufficient number of relevant respondents to conduct academic research in today's busy business world.

Based on the observations gained through the summarization of evaluation results presented in Table 14 within the sixth thesis chapter, the author thinks that the participating project management experts rated all proposed use cases very precisely. Because the maximum possible score is 45 points but the average total rating of all use cases is only 22,25 points. An interesting tendency can be also observed: "The more years of project management practice and the less awareness about Blockchain technology the respondent has, the more skeptically the respondent's evaluation rate is." Therefore, it can be stated that in general the survey's respondents were sceptical against the proposition of new innovative ways of managing projects with the aid of Blockchain technology.

Another interesting observation was made based on total evaluation ratings by each respondent. The evaluation results were partly influenced by the cultural background where the respondents have work practice. During the summarization of the survey's results it was observed that 2 respondents gave slightly higher ratings to all proposed use cases than the other 5 respondents. The thesis author ascribes the rating of these two respondents to their open mind-ser against the proposed alternative use cases of Blockchain technology application than as was the case with other participating respondents. These two more enthusiastic respondents have work experience in USA and Canada, where people in general are more open to new ideas and ways of doing things differently as well as are not afraid of failures. The similar finding was observed within the Global Blockchain Survey 2018 provided by Deloitte. According to Deloitte's Blockchain survey, the stagnant perceptions about Blockchain's capabilities appear to be more entrenched in European countries than in United States (Deloitte, 2018). Amid Global Blockchain survey performed by Deloitte the respondents were asked "*if they believed that Blockchain was just "a database for money" with little application outside of financial services"* (Deloitte, 2018). *"Only 18 % of respondents from USA agreed with that statement versus 61% of respondents in France and the United Kingdom*" (Deloitte, 2018).

8.1.2 Use cases evaluation results

The procedure of the experts' assessment of the proposed use cases was explained in the sixth chapter of the thesis in the section named *Evaluation results*. Based on the total ratings gained by the summarization of the average values by criteria and solution complexity the considerations of the proposed use cases can be sorted in a descending order by their relevance:

1. Cost management,
2. Requirements management,
3. Quality management,
4. Scheduling and milestone tracking,
5. Issue & Change management,
6. Rewarding system,
7. Base for lessons learned,
8. Project closing.

The proposed use cases were sorted in a descending manner by a total rating and were additionally divided by the author into three groups describing their level of relevance:

- **Top.** This group includes 3 the most relevant and useful Blockchain use cases that had been identified within the thesis survey.
- **Medium.** The second group consists of 3 use cases with the total rating under 20 points that are also closer to the total average rating for all proposed use cases: Scheduling and milestone tracking, Issue & Change management and Rewarding system.
- **Bottom.** The Bottom group is presented by 2 use cases with the lowest rating.

Cost management

From the beginning the author expected that the Cost management will gain the highest rating than other proposed use cases. It is a natural result, because today people perceive the Blockchain in relation with financial services due to its disruptive potential and wide adoption mainly in financial sector. That is why for the majority of respondents the Cost Management seems to be a more business viable and technically feasible solution.

Based on these feedbacks, it can be concluded that there are still some unresolved and uncertain aspects to remain. In the author's opinion, there is a necessity to investigate into current trends of Cost management and Blockchain technology capabilities.

The following are feedbacks provided by the survey's respondents regarding the Cost management solution:

- "*I do not think that the technology can help with estimates. However, use of smart contracts can streamline some of the steps with regards to payments. Potential use of crypto currencies in this context might be an interesting research topic. That is why I scored the question no. 9 as "high". However, I view this as a potential impact on the PM domain because there are still many unknowns.*"

- "*Might be suitable only for FTFP external deliverables, less for body shoppers. Note that current trend in project management is more focused od EVM then on spending control.*"

Requirements management and Quality management

The use cases suggested for Requirements management and Quality management were included in the Top group as they gained the same high number of points. The second place in the Top group belongs to Requirements management because project management experts acknowledge it as less complex than the Quality management solution. The solutions proposed within these use cases suggest some alternative approaches to dealing with difficulties arising during managing project requirements and quality of the project outcomes. However, the author did not suppose that these use cases will be rated higher than the Rewarding system solution as an example. Because in the author's opinion, the solution proposed for Rewarding system has more disruptive potential than other suggested use cases of the Blockchain technology application. The Requirements and Quality management are both project aspects which have a significant impact on the project's success. Alongside with it they are tightly and directly connected to each other, since the quality of the project output is defined through customer's requirements. Based on the research dealing with the analysis of actual project management problems performed within this thesis, the author also assumes that:

- these two project management procedures still remain current,
- any new improvements made towards the resolution of existing difficulties are always valuable in form of the best practices.

Therefore, the author considers that the high rating gained by these two solutions can be possibly influenced by the relevance of the project management problems suggested to be resolved within the proposed use cases than by the appropriateness of Blockchain technology application.

Although the feedbacks provided by the respondents with the survey regarding these two use cases also seem more arguable and sceptical. They can be used for the further analysis within the follow-up researches in continuation of the work performed.

The feedbacks provided by the respondents on the matter of the use case for Requirement management:

- "*I do not think that the stated problems can be addressed with technology. However, Blockchain might be beneficial for the requirements management. The suggested use of smart contracts is interesting. It might be also interesting to further investigate possibilities to use smart contracts to evaluate implementation of the requirements based on the available test results, especially in the context of the software development projects. I can imagine use of such requirements tracking for the open source projects as well, so for the question no. 11 I would say both options are viable.*"

- "*Solution is too simplistic, and does not address again the root cause. Also, I do not see how Blockchain could add value as a technology here.*"

- *"I would suggest the requirements management application of block chain technology would be good for both Public and LARGE Private projects in domains where regulation is high aviation, nuclear power, health related, etc.)."*

The feedbacks provided by respondents on the matter of Blockchain use case for Quality management:

- "*The use case for Blockchain is not necessarily project management specific because for me the value added would arise mostly from the ability to track the lifecycle of some products and all of its components. It might vary between industries and particular use cases, but in general I think that it would not be completely easy solution to build and maintain because it would require reliable data about the products, components and probably about the process of production as well.*"

- "*Quality management is strongly dependent upon agreed workflow and usually well organized testing. User interface might be bottleneck for new technologies in this segment. Large corporations use proven solutions.*"

- "*I do not see how Blockchain technology compare to other technologies can add extra value that results in handling hypothetical problems.*"

- "*Both public and private projects seem equally viable.*"

- "*Within domains like aerospace, the integrator of an aircraft (or system) will typically deal with quality for the most important components directly (and privately) with the supplier. Having a centralized ledger is interesting for the integrator to keep track of overall delivery, but the distribution of quality information on suppliers to other competitors may be intentionally restricted.*"

Scheduling and milestone tracking and Issue & Change management

The use cases proposed for Scheduling and milestone tracking and Issue & Change management belong to the second group determining the medium relevance of the proposed solutions. These two suggested use cases were mainly inspired by existing blockchain-based solutions for the supply chain area. There are more analogical similarities of the issues that are being solved on the basis of the Blockchain technology. Therefore, the author of the thesis sees these solutions as more business viable than solutions proposed for Requirements management and Quality management. However, the majority of the project management experts participated within the evaluation survey considered otherwise. The author thinks that the lower rating given by respondents to these two use cases had been influenced by the wide offer of traditional solutions. The author supposes that some advanced project management tools offered currently are able to completely satisfy the current needs of project managers. Scheduling and milestone tracking it is a fundamental functionality of the all existing project management tools. The Issue & Change management can be defined through definition of the lifecycle for each project task. This option is also provided within the majority of existing traditional project management solutions today.

Based on the feedbacks provided by the respondents regarding these two issues can be concluded that for the project management solutions such as Project scheduling and Change management a transparent, intuitive and useful implementation of the user interface matters. As with the aid of the good user interface implementation it is possible to eliminate some issues concerning human behavior. Furthermore, the author of the thesis supposes that the use cases proposed for Scheduling and milestone tracking and Issue & Change management need to be prototyped on the basis of Blockchain technology. These prototyped solutions should be presented to the project managers for more substantive discussion on this matter.

The feedbacks provided by the respondents on the matter of Blockchain use case for Scheduling and milestone tracking:

- *"Immutability might work for the set baselines, however for the schedules under preparation it might bring unnecessary complexity resulting from storing of data that had been relevant only for some interim version of the schedule. The key question would be how to ensure that the data recorded on the ledger corresponds with the real progress of projects. IMHO, the solution description implies private projects."*

- *"Blockchain for this case is not the solution, the underlying problem and root causes could be several different things that are not technology related but human behaviour and habits (not even trust)."*

- *"This application is very interesting, but I would like to know more about how the interface used to deploy Blockchain technology will work. Logging transactions, work completed, deliveries etc... then analysing and managing activities through this technology will require simple and elegant software design. Questions 7 and 8 will depend a lot on how the software around this technology is implemented - without knowing more about the design of the interface is it hard to compare to existing options. Poor software design or implementation may prove barriers to adoption of the technology."*

The respondents' feedbacks regarding the proposed Issue & Change management solution:

- *"The technology can help to keep the records more organized. There might be some benefit from the immutability, however any agreed upon solution to keep and share the information should work. I think that solving issues and managing changes requires appropriate processes and in the end it all depends on the people involved."*

- *"OK, when we talk about Blockchain we are talking first about transaction, then about proof, then about ledger and all these to remove middle man, assuming the middle man is a Project Manager, then Blockchain itself is not going to solve the issue because of human factor - behaviour. Or maybe it can ... I can see some possibilities in certain areas of a project but not all."*

Rewarding system

The third use case within the Medium group is the solution proposed for the innovative Rewarding system which enables to collect rewards during the project without any central

authority meddling. Prior to the beginning of the evaluation procedure the author of the thesis supposed that this solution would gain a higher rating that actually did. Because it has a high disruptive potential as well as solution suggested for the Project Cost management. Alongside with it collection of the rewards in the form of the cryptotokens or cryptocurrencies is the second popular Blockchain technology application today. Besides that, the proposed solution for rewarding of project members is very different from the existing traditional ways of remuneration.

Taking into consideration the respondent's feedback provided within the evaluation survey a certain doubt regarding this matter was assumed. The author thinks that the violate state of the cryptocurrencies today has some influence on the perception of this use case by respondents. As it was previously mentioned in the thesis section *Blockchain technology by countries* cryptocurrencies are still illegal or restricted in some countries. That fact makes people doubt about the relevance and applicability of the solution that is considered as illegal somewhere.

The feedbacks provided by respondents on the matter of blockchain-based Rewarding system:

- *"I rated this use cases based on its potential to exploit the crypto currencies and tokens. The future will tell if this really is a business viable use case. Impact on the PM domain can range from none to significant. It is too early to tell."*

- "*Rewarding system does not necessarily need.*"

- *"This is a double-edged sword, anything that involves such incentives can become dangerous and in my opinion doesn't really help motivate people to do a better job, unless implemented perfectly / sensitively."*

Base for lessons learned and Project closing

The Bottom group consists of two use cases Base for lessons learned and Project closing. What is interesting is that these two use cases gained the same low number of points. This way they were acknowledged as less relevant than the other proposed use cases.

Considering the respondents' feedbacks, author supposed that hypothetically use cases proposed for Project management and Base for lessons learned are less significant than the other suggested use cases. Because these two project management procedures do not affect the current progress of the project and just present the operations executed when all project work had been done. The author also assumed that these two use cases aroused the valuable questions regarding technical implementation of the solution on Blockchain basis. All these questions can be further analyzed and potentially answered within continuation of this thesis work.

The feedbacks provided by the respondents on the matter of Blockchain use case for Project Closing:

- *"In my opinion this use case would only be feasible if there was reliable data about the previous project lifecycle phases. It would definitely be worth further analysis but my question is whether it would make sense to run Blockchain based smart contracts on top of non-Blockchain based data about the project progress, deliverables etc."*

- *"Project closing is more about administrative tasks and their execution. Usually project management office is in charge to follow project closing stage. Note that closing is handled in different systems and integration would be massive in case of automation. Costs of a new technology would be high and benefits might not convince sponsor."*

The respondents' feedbacks regarding the proposed solution for Base for lessons learned:

- *"I do not see any value added in the use of Blockchain for this kind of knowledge base. I think that it is a rather use case for semantic technologies or artificial intelligence."*

- *"I am not sure how Blockchain contributes better compare to existing solutions."*

Blockchain technology application for managing projects in general

Another noteworthy opinion regarding Blockchain technology application for the project management purposes was obtained from one of two respondents who refused to participate in the thesis questionnaire survey. This respondent did not find all proposed use cases of Blockchain technology application relevant and useful for the project management domain. Since from his perspective of view the projects in general are limited by several number of participating organizations. So he considers it is needless to create and share copies of the same records between these organizations. He however states that he sees only one valuable use case of Blockchain technology application for project management when there is no trust between parties concerned and as well there is some difficulties to find a credible mediator (a specialized project management service). In the respondent's opinion it would make sense for every participant to maintain his own copy of all project records. The respondent also thinks that it doe snot matter greatly for what purpose the solution is implemented: scheduling and milestone tracking or cost management.

The author of the thesis agrees that the elimination of the intermediaries is one of the biggest advantages that Blockchain technology enables against the existing traditional solutions. However, the author also thinks that there are another Blockchain advantages such as persistence, immutability, auditability of the data, democratic peer-to-peer transmission and computational logic that can fit the requirements of the complex projects that the existing solutions are not able to provide. Thinking about already successfully realized blockchain-based solutions as about projects that have specific goals and requirements of particular industries. The blockchain-based solution developed for project management can be considered as a solution with an ability to suit the requirements of various industries at once.

8.1.3 Estimates for Blockchain technology future

The estimates for Blockchain technology future in project management were obtained with the aid of the questionnaire survey and presented by Figure 19 and Figure 20 in the sixth thesis chapter. These estimates illustratively show that Blockchain's future in project management area is currently arguable and hardly predictable. Because the respondents' opinions had been divided between all possible response options. The majority was considered as 3 respondents which is less than half of the survey participants. In the author's opinion, the obtained estimates provide the right view on this topic. Since many factors matter, especially Blockchain technology maturity, existence and availability of the appropriate Blockchain standards and regulatory norms, people's perception and awareness about the Blockchain technology as well as technology adoption across other industries (apart from Financial sector). The estimate of when all these Blockchain technology constraints and difficulties can be potentially resolved is an another difficult foreseeable thing. It directly depends on the interest of organizations to use Blockchain technology and on their willingness to support the technology adoption from the government's side.

Another fact confirming that the presented estimates can be considered as relevant is that it corresponds with Gartner's forecast in the form of hype cycle for Blockchain Business for the 2018 available from Figure 13. Gartner's hype cycle presents globally recognized Blockchain solutions for different industries and periods of reaching plateau of productivity. As can be seen from Figure 13 the majority of the presented blockchain-based solutions might reach plateau on average in 5 years and more (Gartner, Inc., 2018c). Building upon Gartner's forecast it can be concluded that the next five years is a period when organizations are expected to actively invest in the development of blockchain-based solutions for various industries. Therefore, the author of the thesis supposes that next 5 years is a period when appropriate measures focused on addressing existing Blockchain technology constraints must be taken, especially for the development of the globally recognized Blockchain standards and necessary regulatory norms. A further question raised concerning resolution of existing Blockchain technology limitations and difficulties is that if 5 years is sufficient?

Based on the discussion above the author considers to propose the following hypothesises regarding Blockchain technology future:

- *"In the next 5 the existing Blockchain technology obstacles can be resolved in large part."*
- *"In 2024-2030 Blockchain technology will be utilized as a standard solution at least by one industry."*

The author also thinks that after verifying these two stated hypothesis for Blockchain technology future development the more specific hypothesis for particular area of technology application can be made.

In relation to the verification of the Blockchain technology potential in project management area the author of this diploma thesis finds it important to additionally investigate more deeply into each of the 8 identified use cases through systematic formal and practical

inquiries such as: interviews with project management and Blockchain technology experts, brainstorming, prototyping, testing and etc.

8.1.4 Solution design

The seventh chapter of this work deals with creation of the main thesis outcome which is the conceptual design of the Project Cost Management blockchain-based solution. The designed solution is provided in with the aid of 5 UML diagrams such as:

- **Use case** diagram represents the main solutions functionalities.
- **Class diagram** visualizes the key system objects, actors, operations and relationships between them.
- **Sequence diagram** explains the main principles and entire workflow of the applied consensus algorithm.
- **Two Deployment diagrams.** The first diagram is an abstract representation of the permissioned Blockchain network which serves the basis for the implemented project Cost Management solution. The second diagram shows the composition of each network's unit together with accurate description of all its components.

Prior to creation of the particular UML diagrams the author of the thesis has carried out several explorations in order to:

- identify core functionalities of the available traditional tools enabling the Project Cost Management.
- to choose the consensus algorithm which suits requirements of the Project Cost Management solution developed on the basis of the permissioned Blockchain network;
- to select an appropriate Blockchain platform which enables establishment of the permissioned Blockchain network together with chosen incentivization mechanism implementation.

For the identification of the Project Cost Management solution's core functionalities the author explored and tested several presently available tools, such as TimeCamp, Trigger and Hubstaff. For making decision regarding which type of consensus algorithms suits better the requirements of the Project Cost Management blockchain-based solution the author used the summary of existing consensus algorithms provided within the survey paper published in Journal of Information Processing Systems in February of 2018 (Nguyen and Kim, 2018, pp. 122-123). The Blockchain platform for the solution implementation was selected by the author based on quality and amount of available information sources describing the network's architecture and its necessary components. For modelling of the Sequence and Deployment diagrams the author of the thesis mainly used official documentation provided by the Hyperledger Fabric platform. Based on all above, it can be concluded that the provided UML diagrams comply with the Project Cost Management requirements and are developed in accordance with the current capabilities and limitations of the Hyperledger Fabric's platform.

8.2 Thesis limitations

As it was already mentioned in section *Thesis key observations and findings* two experts refused to participate in the thesis survey after accessing the questionnaire form for the reason of its large extent. Alongside within the provided feedback they highly advised to perform the research in the form of personal interviews. The author agreed that online questionnaire has some limits for respondents and the survey executor as well as. The interview enables to obtain more specified and detailed information from respondents regarding the issue with the possibility to ask some additional questions. Therefore, the author considers that for the sake of the continuation of this thesis personal interviews better suit the need of a more complex investigations aimed at a deep analysis of 8 identified use cases and their prototyping.

Another limitation of this work is that the thesis seventh chapter devoted to *Blockchain-based project management software tool* does not include the description of the entire process of the conceptual solution design. It solely presents the outputs of the performed design process and its accurate explanation. The description of the entire conceptual solution development process was not included into the work due to diploma thesis extent limitations. However, the section *Solution design* as a part of the *Discussion* chapter briefly indicates the main steps performed prior the realization of the solution design.

The next thesis weak point is that the conceptual diagrams provided within the seventh chapter were created solely based on the subjective author's view on solution's functionality and considerations about choosing the appropriate Blockchain platform for solution implementation. The author of the thesis did not consult the created diagrams with the Project Management and Blockchain experts. However, it can be done within the continuation of this work.

8.3 Thesis contributions

The author considers that the main and valuable contribution of this thesis is all empirical work performed within the theoretical and practical parts of the thesis focusing on the analysis of the Blockchain technology actual capabilities and potential.

The structure of the theoretical part allows its readers to explore Blockchain technology step by step and look over its current capabilities and different ways of application. The theoretical part of the thesis also provides its readers with the actual state of the Blockchain technology for 2019 presented by four dimensions: countries, industries, organizations and existing challenges. All facts and statistics provided within the thesis theoretical part were drawn solely from actual and reliable sources that are attached within the citations list.

The practical part primarily deals with verification of the Blockchain technology potential in project management domain. The ideas, observations and findings provided in the practical part can be considered as the significant contributions of this thesis work, since this thesis is supposed as the first comprehensive work performed on this matter. Alongside

with offering of new ways of the Blockchain technology application the practical part also engages in evaluation of their relevance and applicability for the analyzed domain.

The additional beneficial outcome of this thesis is a conceptual design of the blockchain-based solution that was acknowledged as the most relevant by project management experts. The designed solution is provided in the form of UML diagrams that abstractly indicate its main functions, necessary data inputs and outputs, system processes as well as applied functional advantages of the Blockchain technology. The designed UML diagrams may be helpful as a pattern for the visualization of the other proposed blockchain-based solutions for project management or for illustration of the other similar systems.

Conclusion

For the last three years the Blockchain technology is the most trending topic due to its disruptive potential to reshape various industries. Several solutions have been already successfully applied in the financial sector, insurance, supply chain, public sector and other. However, the potential of using the Blockchain technology in project management domain is not completely recognized up till now.

The main aim of this diploma thesis is to analyse the potential of using Blockchain technology in the project management domain. In order to achieve the primary thesis objective was broken down into five measurable secondary objectives:

1. Execution of the research for existing blockchain-based services.
2. Realization of the research for actual project management problems.
3. Identification of the potential Blockchain use cases for the project management domain.
4. Evaluation of the business viability and the technical feasibility of the identified use cases.
5. Design of the most relevant Blockchain use case for project management purpose.

The first four secondary objectives were achieved through the comprehensive empirical work performed in three stages. The first stage was aimed at the collection and analysis of the existing blockchain-based services and actual problems arising during managing projects. All gathered information was further analysed in order to produce the structural thesis outputs such as:

- list of available blockchain-based services categorized under three categories that serve as a general overview of the functional and technological services capabilities together with needs and requirements that they solve.
- traceability matrix with identified project management problems covered by used information sources.

The second stage of the empirical work was focused on the mapping based on the analogy between the defined blockchain-based services categories and identified project management problems. As a result of the mapping procedure are 8 alternative Blockchain use cases for project management domain. Furthermore, each identified Blockchain use case is accurately formulated with a description of the solution's functionality, problems that it solves and benefits of using.

The third stage of the empirical research is dedicated to the verification of the relevance and applicability of the 8 proposed Blockchain use cases through evaluation under specified set of assessment criteria. The evaluation procedure was performed with the aid of online questionnaire survey focusing to reach project management experts. After getting sufficient number of experts' opinions, the evaluation results were summarized and further analysed.

Each thesis secondary objective was achieved through creation of the particular thesis outputs which are provided solely in accordance with the indicators defined in the Introduction chapter.

The main finding of this diploma thesis is the revelation of the Top 3 the most relevant and applicable Blockchain use cases for project management domain:

1. Cost management,
2. Requirements management,
3. Quality management.

The considered main thesis outcome is the designed solution for the most relevant Blockchain use case. The designed solution for the Project Cost Management is provided in conceptual form within this thesis work. The several UML diagrams give an accurate illustration of the blockchain-based solution layers describing:

- solution's functionality,
- its essential internal processes,
- necessary data inputs and outputs,
- incentivization mechanism used for reaching consensus between parties involved,
- permissioned Blockchain network architecture.

This thesis work can be considered as a first valuable attempt to discover the potential of Blockchain technology in the area where it had not been done yet. The analysis was performed in order to categorize presently existing blockchain-based services and applications. It can further be used as a basis for the exploration of other Blockchain technology directions. The thesis observations and findings gathered during the execution of the several empirical researches can be interesting for companies investing into the Blockchain technology, offering blockchain-based solutions as well as for educational organizations.

The major thesis benefit is the proposition and evaluation of 8 new Blockchain use cases which can potentially fit the requirements of the project management domain. The author of the thesis believes that the future continuation of the work may deal with the complex investigations aimed at a deep analysis of the applicability and technological implementation as well as prototyping of the 8 proposed use cases.

The author of the thesis suggest the following Blockchain technology related topics to follow up this thesis work:

1. The main Blockchain technology challenges and its resolution.
2. Analysis of the existing Blockchain platforms and selection of the most suitable for enterprise solutions development.
3. The analysis and comparison of the blockchain-based and traditional solutions for financial sector/ supply chain /or other specific areas.

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Appendix

This thesis section consists of the documents that were not included in the main text of the work due to their large extent. However, these documents play an important role in this diploma thesis because they present the main outputs from the first and third stages of the empirical research performed within this work.

Appendix A: Full overview of the existing Blockchain-based services

The appendix "Full overview of the existing Blockchain-based services" is attached to the thesis in a digital form. Because it is a large table that is unsuitable to be printed within the work. Therefore, for clarity and more comfortable manipulation with the data the table is provided as an Excel file attached separately to the thesis.

The attached table represents a full overview of the existing blockchain-based services that have been already applied in various areas or existing for now as concept use cases. The structure of the table consists of the following fields:

- **Category 1, Category 2, Category 3** - these table fields specify the category levels, that had been given to the collected blockchain-based services after the categorization process performed within the first stage of the empirical research.
- **Name of the service** – this field simply determines the name of the Blockchain-based services;
- **Service type** - this field includes the differentiation of the Blockchain-based services between two types: existing solution and concept use case. The defined type concept use case means that the service exists in a concept for a current moment;
- **Area** – this table field specify the area, where the Blockchain-based service has been already applied. In the cases of the concept idea the filed represents the are where the service can be potentially applied;
- **Description** – this table field includes the short description of the blockchain-based service, that was taken from the source of the information;
- **Owner of the service / Use-full link** – these last four table fields contain the links to the main source of the information. In some cases, the link refers directly to the page of the service owner, in the remaining cases it is a reference to the secondary useful sources.

The data gathered in this table describe the state of the currently available blockchain-based services as of end of the 2018.

Appendix B: Empty questionnaire form

This appendix represents an empty questionnaire form created within the the third stage of the empirical research for the needs of the evaluation of the 8 proposed use cases of using Blockchain technology in the project management domain. The questionnaire had been prepared via Google forms tool and sent via an online link to the project managers for the gathering of their expert opinions. The questionnaire' content is further described in the *Survey workflow* section of the sixth thesis chapter.

Evaluation of the potential use cases of using Blockchain technology in Project Management domain

The main aim of the survey is verification of the potential of using the Blockchain technology for the Project Management domain. The survey presents 8 different use cases that theoretically can be suitable to be implemented on the base of the Blockchain technology for specific Project management purposes. Each use case is accurately descripted including the problems that it resolves and benefits that it brings. The survey allows respondent(s) to evaluate each use case under the special set of evaluation criteria needed to assess business viability and technical feasibility of the proposed solutions. Based on the survey results the solution for the most suitable use case will be designed and presented within the diploma thesis that will be defended in June of 2019 at University of Economics in Prague.

Please notice, that:

- Filling the questionnaire may take approximately about 30–40 minutes.

- The survey is anonymous. You can put your name optionally. It's need just for the identification purpose. Your personal data will not be associated with the evaluation results and will not be published in the thesis as well.

For the case of need, under the following link you can find a brief explanation about Blockchain technology:

https://docs.google.com/document/d/1XyYEpHQWzQ0-8nuj37rgY38tLyz5uTGQxgjHrjwIU-I/edit?usp=sharing

Please, tell about yourself

Your name (optional):

How many years of project management experience do you have? *

In which area(s) do you manage projects? *

Please describe your awareness about Blockchain technology. *

	1	2	3	4	5	
Low	◯	◯	◯	◯	◯	High

Evaluation of the 1. use case

For the better view of the use case description please use the following link: https://docs.google.com/spreadsheets/d/1epei0bfo7K_WTWk_wxifkYXHmakcmkML7qY2wJBQx-w/edit?usp=sharing

Scheduling & milestone tracking (supplier inputs included)

Problems to resolve	For what type of projects	Solution description	Benefits
- Lack of continuous monitoring and tracking of project objectives in real-time; - Insufficient stakeholder awareness;	Large projects with a wide scope and complex deliveries. Such projects have hundreds of milestones, inputs and outputs of key suppliers. Therefore, there is a need to continually monitor and controll the progress of the project. *For example: complex IT projects, manufacturing project.*	***Scheduling & milestone tracking (supplier inputs included)*** *Trusted Blockchain Network with all participants involved: customers, project lead, project team, sponsors, executives, steering committee, key suppliers and etc. The Blockchain technology records everything in transactions as the historical register of every meaningful indicator, even the development of a project.* Blockchain-powered scheduling and milestone tracking solution enables all involved participants to oversee the project real-time progress in detail. The precise and detailed planned project schedule is shared between all stakeholders. The level of detail can be regulated by roles of the participants by Blockchain's permissions. Blockchain technology does not let to change planned schedule, but allows all participants to track in detail the actual project progress in real-time. Transactions related to the project progress are recorded with the actual time-stamp in the moment when it happened. Blockchain Network allows project members to track the start and finish of the project phases, status changes of the important tasks and project milestones in a transparent way. So all project participants have opportunity to be aware of the actual state of the project "up-to the-minute". Each project progress transaction can be completed with the information about delays or completion ahead of time, that enable to monitor how the project develops in comparison with the planned schedule. Transactions about delivery of supplier inputs can be also integrated to the main project schedule. Supplier delay can cause delays in project, because project deliverables often directly depend on the supplier inputs. If this information would be tracked within the main project schedule, it can help not only to take prevent measures in time but also to improve Issue & Change management and Resource allocation management.	- Trusted collaboration platform for better awareness about project progress; - All project information is kept in records and can not be changed or lose; - Data can be used for the analysis in Post-Project review

Evaluation criteria

1. Suitability of the 1. use case for Blockchain technology application. *

	1	2	3	4	5	
Low	◯	◯	◯	◯	◯	High

2. Problem resolution arising from using Blockchain technology described within the 1. use case. *

	1	2	3	4	5	
Low	◯	◯	◯	◯	◯	High

3. Utilisation of Blockchain technology advantages (consistency, transparency, auditability, persistence, immutability and irreversibility) within the 1. use case. *

	1	2	3	4	5	
Low	◯	◯	◯	◯	◯	High

4. Business viability of the 1. use case from the Project management perspective. *

	1	2	3	4	5	
Low	◯	◯	◯	◯	◯	High

5. Technical feasibility of the 1. use case from the solution development perspective. *

	1	2	3	4	5	
Low	◯	◯	◯	◯	◯	High

6. Operational complexity of the 1. use case (amount of the data, amount and complexity of relationships, complexity of user behaviour). *

	1	2	3	4	5	
Low	◯	◯	◯	◯	◯	High

7. Comparative advantage of the 1. use case in comparison with the currently offered PM solutions. *

	1	2	3	4	5	
Low	◯	◯	◯	◯	◯	High

8. Disruptive difference in approach of the 1. use case compared to currently offered PM solutions. *

	1	2	3	4	5	
Low	◯	◯	◯	◯	◯	High

9. Impact of the innovative way of doing things differently proposed in the 1. use case on the Project management domain. *

	1	2	3	4	5	
Low	◯	◯	◯	◯	◯	High

10. Do you find the solution proposed within the 1. use case interesting and useful for to be applied at least on one of your projects? *

- ◯ Yes
- ◯ No

11. In your opinion, is the 1. use case more suitable for to be implemented for projects running openly in public (anyone can join and see the data) or for private projects running under restricted permissions and specified privacy level(s)? *

- ◯ Public projects
- ◯ Private projects

Place for your comment/feedback for the 1. use case (optional).

Evaluation of the 2. use case

For the better view of the use case description please use the following link: https://docs.google.com/spreadsheets/d/1epei0bfo7K_WTWk_wxifkYXHmakcmkML7qY2wJBQx-w/edit?usp=sharing

Requirements management

Problems to resolve	For what type of projects	Solution description	Benefits
- Poor requirements management; - Unclear specification of requirements; - Overlapping requirements; - Duplicating requirements; - Change of the project scope; - Quickly changing customer requirements; - Unrealistic customer expectations;	Large projects that involve integrating a wide scope of products and services into a total solution to meet the customer's complex and unique needs. There is a need for: precise and detail requirement specification, historical traceability of requirements, requirement status tracking, trace requirements relationships. *For example: complex IT project targeted to produce a technical device, that comprises hardware and software development.*	***Requirements management*** *Trusted Blockchain Network with all participants involved: customers, project lead, project team, sponsors, executives, steering committee and etc. The Blockchain technology records everything in transactions, that are highly structured, transparent, invariable, safe, verifiable. It can be used for the successful requirements management that exactly requires a highly structured and transparent register of information about customer needs and expectations.* Blockchain-based way how to manage customer requirements lies in transformation of the interaction process between customer and project team. In the initiation stage of the project all accepted customer requirements with detailed specification, relationships and priorities are shared between all stakeholders. All new requirements coming during the project are also distributely stored as transactions with the same attributes as requirements at the start of the project. New requirements after creation gains automatically status "Proposed". After acceptation by business analysts and developers the status changed to "Approved" or "Rejected". So that way all incoming requirements are historically traceable and well categorized. When the requirement gains the status "Approved" it means that the relationships and dependencies had been analysed and already set. The relationships and dependencies between requirements can be implemented with use of Smart Contracts. So change of the one requirement can trigger a chain of changes to other requirements. The Blockchain-based solution for managing customer requirements allows to provide the latest statuses and other data attributes of individual requirements. All project participants would be always aware about such changes. The project outputs would be always delivered in consistent and expected format.	- Paperless Requirements management without endless cycle of rework such as reviews in the form of a document or spreadsheet; - Online approach makes it easier for distributed and virtual cooperation with customer and alongside for project team members as well; - Enabling teams to communicate the appropriate level of project scope in the more efficient way; - Better traceability of the requirements;

Evaluation criteria

1. Suitability of the 2. use case for Blockchain technology application. *

	1	2	3	4	5	
Low	◯	◯	◯	◯	◯	High

2. Problem resolution arising from using Blockchain technology described within the 2. use case. *

3. Utilisation of Blockchain technology advantages (consistency, transparency, auditability, persistence, immutability and irreversibility) within the 2. use case. *

4. Business viability of the 2. use case from the Project management perspective. *

5. Technical feasibility of the 2. use case from the solution development perspective. *

6. Operational complexity of the 2. use case (amount of the data, amount and complexity of relationships, complexity of user behaviour). *

7. Comparative advantage of the 2. use case in comparison with the currently offered PM solutions. *

8. Disruptive difference in approach of the 2. use case compared to currently offered PM solutions. *

9. Impact of the innovative way of doing things differently proposed in the 2. use case on the Project management domain. *

10. Do you find the solution proposed within the 2. use case interesting and useful for to be applied at least on one of your projects? *

- ◯ Yes
- ◯ No

11. In your opinion, is the 2. use case more suitable for to be implemented for projects running openly in public (anyone can join and see the data) or for private projects running under restricted permissions and specified privacy level(s)? *

- ◯ Public projects
- ◯ Private projects

Place for your comment/feedback for the 2. use case (optional).

Evaluation of the 3. use case

For the better view of the use case description please use the following link: https://docs.google.com/spreadsheets/d/1epei0bfo7K_WTWk_wxifkYXHmakcmkML7qY2wJBQx-w/edit?usp=sharing

Quality management

Problems to resolve	For what type of projects	Solution description	Benefits
- Poor quality control; - Different perceptions about quality; - Absence of the supplier quality assurance requirements; - Inspection over prevention; - Lack of continuous improvement; - Customer dissatisfaction with the quality of project outcomes;	Large projects that cooperated with a several number of suppliers. There is a need to check quality of service, row material alongside with a single product part or finished product. The same applies to project outputs as well. *For example: complex projects in technology, automobile, aviation areas etc.*	***Quality management*** *Trusted Blockchain Network with all participants involved: customers, project lead, project team, sponsors, executives, steering committee and key suppliers etc. Blockchain technology is a distributed decentralized and immutable ledger that makes secure and prolific transactions. With relying on shared data and immutable ledger the project team can prove that agreed quality is being delivered as well as to validate the quality of the supplier inputs.* Blockchain technology-based project quality management is about optimal investment in conformance cost. The main goal is to adjust project processes for making quality control an integral part of everyday activities. With the aid of Blockchain technology it is possible to "set" the project quality level by systematically managing all activities in a way to achieve a specified level of quality. As opposed to traditional projects in which the contrary approach is applied (the quality activities are defined). By connecting IoT and Blockchain technology is possible to incessantly validate the quality of the supplier inputs. The same approach can be used for the all project deliverables produced by project team. It can be realized by measuring project outputs and gathering data prior to pilot testing within Blockchain. Further these results can be compared and detailed analysed to track measurable improvement of the project outputs. The other possibility is the usage of Smart Contracts, that serve as the independent quality Gateway for the final project deliverables, which is triggered based on definition of the target state of the project main outputs.	- Track measurable improvement of the project deliverables; - Contribute to rise customer satisfaction not only with quality of project outputs but with the whole delivery process as well; - The transparency and specificity of the blockchain-based solution help build trust in the quality of the project outcomes; - Prevention over inspection. It's better to pay cost of conformance than and cost of non-conformance;

Evaluation criteria

1. Suitability of the 3. use case for Blockchain technology application. *

	1	2	3	4	5	
Low	◯	◯	◯	◯	◯	High

2. Problem resolution arising from using Blockchain technology described within the 3. use case. *

	1	2	3	4	5	
Low	◯	◯	◯	◯	◯	High

3. Utilisation of Blockchain technology advantages (consistency, transparency, auditability, persistence, immutability and irreversibility) within the 3. use case. *

	1	2	3	4	5	
Low	◯	◯	◯	◯	◯	High

4. Business viability of the 3. use case from the Project management perspective. *

	1	2	3	4	5	
Low	◯	◯	◯	◯	◯	High

5. Technical feasibility of the 3. use case from the solution development perspective. *

	1	2	3	4	5	
Low	◯	◯	◯	◯	◯	High

6. Operational complexity of the 3. use case (amount of the data, amount and complexity of relationships, complexity of user behaviour). *

	1	2	3	4	5	
Low	◯	◯	◯	◯	◯	High

7. Comparative advantage of the 3. use case in comparison with the currently offered PM solutions. *

	1	2	3	4	5	
Low	◯	◯	◯	◯	◯	High

8. Disruptive difference in approach of the 3. use case compared to currently offered PM solutions. *

	1	2	3	4	5	
Low	◯	◯	◯	◯	◯	High

9. Impact of the innovative way of doing things differently proposed in the 3. use case on the Project management domain. *

	1	2	3	4	5	
Low	◯	◯	◯	◯	◯	High

10. Do you find the solution proposed within the 3. use case interesting and useful for to be applied at least on one of your projects? *

- ◯ Yes
- ◯ No

11. In your opinion, is the 3. use case more suitable for to be implemented for projects running openly in public (anyone can join and see the data) or for private projects running under restricted permissions and specified privacy level(s)? *

- ◯ Public projects
- ◯ Private projects

Place for your comment/feedback for the 3. use case (optional).

Evaluation of the 4. use case

For the better view of the use case description please use the following link: https://docs.google.com/spreadsheets/d/1epei0bfo7K_WTWk_wxifkYXHmakcmkML7qY2wJBQx-w/edit?usp=sharing

Issue & Change management with flexible problem-solving

Problems to resolve	For what type of projects	Solution description	Benefits
- Lack of awareness and understanding of issue or change; - Solving a different problem the same way; - Poor communication about resolving the problem; - Insufficient consensus between stakeholders;	Large projects interconnected with various elements, with high dependencies to another related projects or another external factors. There is a need to continual monitor project health by identifying and resolving unexpected issues. *For example: Huge regional projects, construction projects.*	***Issue & Change Management with flexible problem-solving*** *Trusted Blockchain Network with all participants involved: customers, project lead, project team, sponsors, executives, steering committee etc. The communication capability of the Blockchain technology enables rapid transfer of information between all participating nodes. At the same time inside Blockchain it's not possible to change the data without it being seen. These Blockchain's advantages can be used for dealing with issue and changes within project management.* The potential of creating issue and change log on Blockchain lies in awareness of all stakeholders about issues and involving them into flexible problem-solving process. Integration of customers, vendors, project sponsors and project team into the Blockchain Network will make easier managing issues such as problems or changes. The key for successful issue management is well-timed awareness about the problem or change. Within Blockchain network any modification in the project such as component deficiency reports and resource change are currently displayed in each participating node. Furthermore, within Blockchain Network all participants can be simultaneously required to attend the collective problem-solving for enabling the continuation of the project. It can be performed with the use of Smart Contracts and the blockchain-based approval tool. The problem-solving action can be initiated with dependence to the issue attributes (status, priority, type, deadline etc.). allowing all parties involved to make informed decision based on a common set of trusted data. The Blockchain-based solution for managing issue and changes allows to provide the latest statuses and other data attributes of the issue. All project participants would be always aware about problems and can contribute by participation in collective problem-solving as whether the issue shall be solved or the change shall be executed.	- Eliminate possible negative impacts on the project; - Reduced risk; - Greater effectiveness by reducing the need to organize meetings and third-party engagement; - Increase flexibility in decision-making by removing bureaucracy and intermediaries; - Higher success rate; - Record issue resolution for future reference and project learning;

Evaluation criteria

1. Suitability of the 4. use case for Blockchain technology application. *

	1	2	3	4	5	
Low	◯	◯	◯	◯	◯	High

2. Problem resolution arising from using Blockchain technology described within the 4. use case. *

	1	2	3	4	5	
Low	◯	◯	◯	◯	◯	High

3. Utilisation of Blockchain technology advantages (consistency, transparency, auditability, persistence, immutability and irreversibility) within the 4. use case. *

	1	2	3	4	5	
Low	◯	◯	◯	◯	◯	High

4. Business viability of the 4. use case from the Project management perspective. *

	1	2	3	4	5	
Low	◯	◯	◯	◯	◯	High

5. Technical feasibility of the 4. use case from the solution development perspective. *

	1	2	3	4	5	
Low	◯	◯	◯	◯	◯	High

6. Operational complexity of the 4. use case (amount of the data, amount and complexity of relationships, complexity of user behaviour). *

	1	2	3	4	5	
Low	◯	◯	◯	◯	◯	High

7. Comparative advantage of the 4. use case in comparison with the currently offered PM solutions. *

	1	2	3	4	5	
Low	◯	◯	◯	◯	◯	High

8. Disruptive difference in approach of the 4. use case compared to currently offered PM solutions. *

	1	2	3	4	5	
Low	◯	◯	◯	◯	◯	High

9. Impact of the innovative way of doing things differently proposed in the 4. use case on the Project management domain. *

	1	2	3	4	5	
Low	◯	◯	◯	◯	◯	High

10. Do you find the solution proposed within the 4. use case interesting and useful for to be applied at least on one of your projects? *

- ◯ Yes
- ◯ No

11. In your opinion, is the 4. use case more suitable for to be implemented for projects running openly in public (anyone can join and see the data) or for private projects running under restricted permissions and specified privacy level(s)? *

- ◯ Public projects
- ◯ Private projects

Place for your comment/feedback for the 4. use case (optional).

Evaluation of the 5. use case

For the better view of the use case description please use the following link: https://docs.google.com/spreadsheets/d/1epei0bfo7K_WTWk_wxifkYXHmakcmkML7qY2wJBQx-w/edit?usp=sharing

Cost management

Problems to resolve	For what type of projects	Solution description	Benefits
- The cost estimate for the entire project is no reliable; - Over budgeting; - Cost accounting, not cost analysis; - Reduced opportunity to decrease the cost during the project delivery process;	Large projects for which it is difficult to estimate the cost due to their uniqueness. There is a need to constantly collect, analyse, evaluate and reporting the cost information for budgeting, improving estimates, forecasting and monitoring costs. *For example: large project from energy, nuclear energy areas.*	***Cost management*** *Trusted Blockchain Network with all participants involved: customers, project lead, project team, sponsors, executives, steering committee key suppliers etc. Blockchain technology is a new path in transmitting both sensitive data and secure payments with trust and without additional fees. Alongside Blockchain enables to automatically execute business contracts between several business parties as well. All these opportunities can satisfy needs of the Project Cost Management.* Blockchain-based Cost Management solution lies in cost scheduling with the lower levels of the cost breakdown structure (CBS) and implementation of the Smart contract payments. The detailed planned project cost item-by-item supplemented with terms is shared between all stakeholders. Blockchain technology does not let to change planned CBS but allows all participants to track in detail the actual cost usage in real-time. It can be performed by implementing Smart Contracts in the each project phase, milestone or scheduled action to to handle automatically payments to supplier organizations, subcontractors and project team members. The peer-to-peer database first captures all terms and conditions of the agreed digital contracts, then uses data gleaned across distributed nodes during the project to determine when those conditions have been fulfilled and then the payment is authorized. So that transactions related to the cost usage are recorded with the actual time-stamp in the moment when they were just spent. Blockchain-based solution allows to manage cost within the current budget and current forecast by reviewing spent cost items side by side with the planned budget. It provides the clear understanding of what exactly went into the current budget and current forecast. The Blockchain-based solution for the Project Cost management has also an ability to reflect money spent on unexpected issues or changes. It can create a distinct group of cost, that can be tracked separately.	- Distributed, transparent, historical overview of economic transactions; - Real-time cost management; - Improve calculation of the estimation and forecast cost; - Allowing to avoid transaction fees;

Evaluation criteria

1. Suitability of the 5. use case for Blockchain technology application. *

	1	2	3	4	5	
Low	◯	◯	◯	◯	◯	High

2. Problem resolution arising from using Blockchain technology described within the 5. use case. *

	1	2	3	4	5	
Low	◯	◯	◯	◯	◯	High

3. Utilisation of Blockchain technology advantages (consistency, transparency, auditability, persistence, immutability and irreversibility) within the 5. use case. *

	1	2	3	4	5	
Low	◯	◯	◯	◯	◯	High

4. Business viability of the 5. use case from the Project management perspective. *

	1	2	3	4	5	
Low	◯	◯	◯	◯	◯	High

5. Technical feasibility of the 5. use case from the solution development perspective. *

	1	2	3	4	5	
Low	◯	◯	◯	◯	◯	High

6. Operational complexity of the 5. use case (amount of the data, amount and complexity of relationships, complexity of user behaviour). *

	1	2	3	4	5	
Low	◯	◯	◯	◯	◯	High

7. Comparative advantage of the 5. use case in comparison with the currently offered PM solutions. *

	1	2	3	4	5	
Low	◯	◯	◯	◯	◯	High

8. Disruptive difference in approach of the 5. use case compared to currently offered PM solutions. *

	1	2	3	4	5	
Low	◯	◯	◯	◯	◯	High

9. Impact of the innovative way of doing things differently proposed in the 5. use case on the Project management domain. *

	1	2	3	4	5	
Low	◯	◯	◯	◯	◯	High

10. Do you find the solution proposed within the 5. use case interesting and useful for to be applied at least on one of your projects? *

◯ Yes
◯ No

11. In your opinion, is the 5. use case more suitable for to be implemented for projects running openly in public (anyone can join and see the data) or for private projects running under restricted permissions and specified privacy level(s)? *

- ◯ Public projects
- ◯ Private projects

Place for your comment/feedback for the 5. use case (optional).

Evaluation of the 6. use case

For the better view of the use case description please use the following link: https://docs.google.com/spreadsheets/d/1epei0bfo7K_WTWk_wxifkYXHmakcmkML7qY2wJBQx-w/edit?usp=sharing

Project closing

Problems to resolve	For what type of projects	Solution description	Benefits
- Never ending project; - Stakeholders do not realize that the project is over and continue treat it as an active project; - Negative perception of project team efforts for matters that are not their fault or responsibility;	Large projects with complex workflow and many deliverables. *For example: software projects, technology projects.*	***Project closing*** *Trusted Blockchain Network with all participants involved: customers, project lead, project team, sponsors, executives, steering committee etc. Blockchain technology is a distributed decentralized and immutable ledger that makes secure and trust transactions. With relying on shared data and immutable ledger the project team can prove that agreed deliverables were being delivered as well as to validate the acceptation of them by customers and sponsors.* Blockchain-based Project Closure procedure is about implementation of the Project Closure Report with use of the Smart Contracts. The Project Closure report would contain the list of activities, in this case the list of digital contracts that are targeted to ensure that project closure is completed smoothly and efficiently. Once the Project Closure Report has been approved by the project sponsor, the closure activities stated in the report are actioned. After that, the project may be closed. Below there is list of closure actions and activities, that can be executed automatically with the use of Smart Contracts to check if the exit criteria are met: * All issues are resolved, * All documents and deliverables are up-to-date, * Acquisition of confirmation about the delivery and formal acceptance of deliverables by the customer, * Ensuring that all costs are charged to the project, * Informing stakeholders of the closure of the project, * Cancelling supplier contracts, * Releasing staff and equipment, * Closing of project accounts.	- Better auditability of project success or failure; - Help to ensure that all the work has been completed in agreed way, all appropriate project management processes have been executed; - Allow to get formal recognition of the completion of a project—everyone agrees that the project is finished;

Evaluation criteria

1. Suitability of the 6. use case for Blockchain technology application. *

	1	2	3	4	5	
Low	◯	◯	◯	◯	◯	High

2. Problem resolution arising from using Blockchain technology described within the 6. use case. *

	1	2	3	4	5	
Low	◯	◯	◯	◯	◯	High

3. Utilisation of Blockchain technology advantages (consistency, transparency, auditability, persistence, immutability and irreversibility) within the 6. use case. *

	1	2	3	4	5	
Low	◯	◯	◯	◯	◯	High

4. Business viability of the 6. use case from the Project management perspective. *

	1	2	3	4	5	
Low	◯	◯	◯	◯	◯	High

5. Technical feasibility of the 6. use case from the solution development perspective. *

	1	2	3	4	5	
Low	◯	◯	◯	◯	◯	High

6. Operational complexity of the 6. use case (amount of the data, amount and complexity of relationships, complexity of user behaviour). *

	1	2	3	4	5	
Low	◯	◯	◯	◯	◯	High

7. Comparative advantage of the 6. use case in comparison with the currently offered PM solutions. *

	1	2	3	4	5	
Low	◯	◯	◯	◯	◯	High

8. Disruptive difference in approach of the 6. use case compared to currently offered PM solutions. *

	1	2	3	4	5	
Low	◯	◯	◯	◯	◯	High

9. Impact of the innovative way of doing things differently proposed in the 6. use case on the Project management domain. *

	1	2	3	4	5	
Low	◯	◯	◯	◯	◯	High

10. Do you find the solution proposed within the 6. use case interesting and useful for to be applied at least on one of your projects? *

- ◯ Yes
- ◯ No

11. In your opinion, is the 6. use case more suitable for to be implemented for projects running openly in public (anyone can join and see the data) or for private projects running under restricted permissions and specified privacy level(s)? *

- ◯ Public projects
- ◯ Private projects

Place for your comment/feedback for the 6. use case (optional).

Evaluation of the 7. use case

For the better view of the use case description please use the following link: https://docs.google.com/spreadsheets/d/1epei0bfo7K_WTWk_wxifkYXHmakcmkML7qY2wJBQx-w/edit?usp=sharing

Base for lessons learned

Problems to resolve	For what type of projects	Solution description	Benefits
- No effective utilization of lessons learned from past project; - Constantly solving the same problem over and over again;	*For every project.*	***Base for lessons learned*** *Trusted Blockchain Network with all participants involved: customers, project lead, project team, sponsors, executives, steering committee etc. Blockchain technology records everything in transactions as the historical register of every meaningful indicator. Distributed storage allows to record and transmit data that are transparent, invisible, secure, controllable, and resistant to outages and hacker attacks and loss.* Blockchain technology serves as a valuable archive for the experience gained and its future analysis, auditing and evaluation purposes. That is what actually needs for storing of the project management intellectual property such as "Lessons Learned" form the past projects. The distributed sharing of information prevents of data lose, unpermissioned changes or deletion. The historical register of the "lessons learned" provides an overview how the resolution of the same problem has been changing over time in order to improve.	- Allow to record lessons learned as they are learned, not rather than waiting until the end; - More precise development of project management standards and templates; - More targeted benchmarking and mentoring;

Evaluation criteria

1. Suitability of the 7. use case for Blockchain technology application. *

	1	2	3	4	5	
Low	◯	◯	◯	◯	◯	High

2. Problem resolution arising from using Blockchain technology described within the 7. use case. *

3. Utilisation of Blockchain technology advantages (consistency, transparency, auditability, persistence, immutability and irreversibility) within the 7. use case. *

4. Business viability of the 7. use case from the Project management perspective. *

5. Technical feasibility of the 7. use case from the solution development perspective. *

6. Operational complexity of the 7. use case (amount of the data, amount and complexity of relationships, complexity of user behaviour). *

7. Comparative advantage of the 7. use case in comparison with the currently offered PM solutions. *

8. Disruptive difference in approach of the 7. use case compared to currently offered PM solutions. *

9. Impact of the innovative way of doing things differently proposed in the 7. use case on the Project management domain. *

	1	2	3	4	5	
Low	◯	◯	◯	◯	◯	High

10. Do you find the solution proposed within the 7. use case interesting and useful for to be applied at least on one of your projects? *

◯ Yes
◯ No

11. In your opinion, is the 7. use case more suitable for to be implemented for projects running openly in public (anyone can join and see the data) or for private projects running under restricted permissions and specified privacy level(s)? *

◯ Public projects
◯ Private projects

Place for your comment/feedback for the 7. use case (optional).

Evaluation of the 8. use case

For the better view of the use case description please use the following link: https://docs.google.com/spreadsheets/d/1epei0bfo7K_WTWk_wxifkYXHmakcmkML7qY2wJBQx-w/edit?usp=sharing

Rewarding system

Problems to resolve	For what type of projects	Solution description	Benefits
- Unmotivated team members; - Poor team spirit; - The team isn't high performing; - Lack of commitment – team members don't commit or buy in to decisions; - Avoidance of accountability – unwilling to discuss performance behaviours; - Inattention to results – not focused on achieving the team's results;	Large projects with a several number of virtual and distant teams. *For example: complex IT projects.*	***Rewarding system*** *Trusted Blockchain Network with all participants involved: customers, project lead, project team, sponsors, executives, steering committee etc. Blockchain technology records everything in transactions as the reliable historical register of every meaningful indicator, even the project performance based on the project progress development.* The idea of the blockchain-based rewarding system is in remuneration of the team for the registered great performance on the project. It can be done in two ways: financial way with the aid of cryptotokens and non-financial. Financial way how to reward: The project team members would have an opportunity to collect cryptotokens during the project for their high performance work and excellent results. Such as tasks completed under budget; deliverables that meet desired quality; participation on problem-solving, extra time etc. By implementation special algorithms with using of Smart Contracts the cryptotokens will be distributed automatically to whole team or to particular team member. Then at the end of the project team members can exchange gained cryptotokens to real money. The exchange rate would depend: on money saved (in case if the project completed under budget) or on the willingness of project sponsors to allocate particular amount to reward project team members. Non-financial way how to reward: Celebration of every meaningful moment of the project, such as the successful end of the project phase, meeting task deadline or milestone. With using Smart Contracts it's possible to automatically send motivated notifications messages with regard to project context when the appropriate conditions would be met.	- Team oriented on performance and focused on results; - Faithful and motivated individuals;

Evaluation criteria

1. Suitability of the 8. use case for Blockchain technology application. *

	1	2	3	4	5	
Low	◯	◯	◯	◯	◯	High

2. Problem resolution arising from using Blockchain technology described within the 8. use case. *

	1	2	3	4	5	
Low	◯	◯	◯	◯	◯	High

3. Utilisation of Blockchain technology advantages (consistency, transparency, auditability, persistence, immutability and irreversibility) within the 8. use case. *

	1	2	3	4	5	
Low	◯	◯	◯	◯	◯	High

4. Business viability of the 8. use case from the Project management perspective. *

	1	2	3	4	5	
Low	◯	◯	◯	◯	◯	High

5. Technical feasibility of the 8. use case from the solution development perspective. *

	1	2	3	4	5	
Low	◯	◯	◯	◯	◯	High

6. Operational complexity of the 8. use case (amount of the data, amount and complexity of relationships, complexity of user behaviour) *

	1	2	3	4	5	
Low	◯	◯	◯	◯	◯	High

7. Comparative advantage of the 8. use case in comparison with the currently offered PM solutions. *

	1	2	3	4	5	
Low	◯	◯	◯	◯	◯	High

8. Disruptive difference in approach of the 8. use case compared to currently offered PM solutions. *

	1	2	3	4	5	
Low	◯	◯	◯	◯	◯	High

9. Impact of the innovative way of doing things differently proposed in the 8. use case on the Project management domain. *

	1	2	3	4	5	
Low	◯	◯	◯	◯	◯	High

10. Do you find the solution proposed within the 8. use case interesting and useful for to be applied at least on one of your projects? *

- ◯ Yes
- ◯ No

11. In your opinion, is the 8. use case more suitable for to be implemented for projects running openly in public (anyone can join and see the data) or for private projects running under restricted permissions and specified privacy level(s)? *

- ◯ Public projects
- ◯ Private projects

Place for your comment/feedback for the 8. use case (optional).

Your suggestions and expectations

Do you see any other potential options of using Blockchain technology for Project management domain? If yes, please specify (optional).

What is your estimate of when the Blockchain technology will be successfully applied in Project management area (at least one organization using Blockchain for managing projects on regular basis)? *

- ◯ Never
- ◯ less than 2 years
- ◯ 2 to 5 years
- ◯ 5 to 10 years
- ◯ more than 10 years

What is your estimate of when the Blockchain will become commonly applied technology in Project management area (wide range of organisations using Blockchain for managing their projects on regular basis)? *

- ◯ Never
- ◯ less than 2 years
- ◯ 2 to 5 years
- ◯ 5 to 10 years
- ◯ more than 10 years

Thank you for your participation in survey!

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Appendix C: Completed questionnaire forms

For the sake of credibility, the author of this thesis work considered it as necessary to provide to the thesis readers all used data sources. Therefore, the questionnaire forms anonymously completed by survey's respondents are also attached to this diploma thesis. Due to its large extent it was not possible to provide it within the thesis content. For this reason, the completed questionnaire forms are provided as a PDF document enclosed together with the entire thesis work.