Project Success Factors and Pitfalls by Using BIM and Data-Driven Construction

Master Thesis

International Master of Science in Construction and Real Estate Management
Joint Study Programme of Metropolia UAS and HTW Berlin

from

Diana Kustdavletova

(S0567950)

Date:

Berlin, 23.12.2020

1st Supervisor: Lic.Sc. Mika Lindholm

2nd Supervisor: Prof. Dr.-Ing. Markus Kraemer

[Acknowledgement]

I would like to express my deepest gratitude to my supervisor Lic.Sc. Mika Lindholm for his guidance, support and patience during the period of this Master Thesis. His valuable comments, advice and directions have helped to go in the right direction during the research and made the process easier.

Also, I want to thank my second supervisor Prof. Dr.-Ing. Markus Kraemer for his support during the research and during my studies.

A special thanks to my family for their emotional support and motivation during this journey.

Finally, thank you to all lovely respondents who were an essential part of this research for their valuable inputs and time spent on the questionnaire and interviews.

[Copy of proposed conceptual formulation]

Metropolia

htw. Hochschule für Technik und Wirtschaft Berlin
University of Applied Sciences

International Master of Science in Construction and Real Estate Management

Joint Study Programme of Metropolia Helsinki and HTW Berlin

Date 01.10.2019

Conceptual Formulation
Master Thesis for Mr./Ms. Diana Kustdavletova
Student number ___________S0567950_____________________

Topic:
Project success factors and pitfalls by using BIM and data driven construction

Background
In order to remain competitive and up to date, the construction industry needs to embrace data driven technologies. Current pace of emerging technological advancements is disrupting the industry and introducing new tools and methods to improve the industry's efficiency. Building Information Modeling (BIM) has come into the scene of the industry promising to treat all the diseases of the industry, including the inefficiency, delays and cost that is out of control, as well as waste that is generated by building activities.

Latest innovations in construction IT such as Artificial Intelligence, Internet of Things, Virtual reality and cloud-based platforms are emerging in the industry and presenting the opportunities to gather accurate data on every aspect of a project, therefore, presenting potential improvement of the construction project management and control.

BIM and data-driven construction provide tools for collaboration and creation of integrated information model, however, BIM is not only a technology, it is also a management process that affects greatly the collaboration between the construction parties, and therefore, making construction more manageable.

Notwithstanding the known attributes and abilities of such tools/processes, as well as the awareness of its tremendous importance, the implementation of them is still rather low. Some reasons behind poor adoption of construction technologies are reported as being lack of demand from Client's side, absence of BIM standard operation procedures, lack of BIM experts, and of course, the cost and effort of implementation.

Metropolia

htw
Hochschule für Technik und Wirtschaft Berlin
University of Applied Sciences

Goal and expected results

In the proposed research study, the author aims to understand which factors affect the overall success of construction projects and find out the contribution of construction IT, BIM and data driven construction in such success. Information Technology for construction industry has a promising potential, it is said to help to produce better project management and contribute to success of projects in terms of project management triangle i.e. improved cost, time and quality management. As a result of this study, the author hopes to come up with recommendations/guideline on the utilization of BIM and data-driven construction projects to help to produce more successful projects. Possible pitfalls of BIM/data will be also identified and analyzed in order to suggest the possible ways to avoid them.

Research methods and materials

In order to collect the information for this research study, the following research methods will be used:

1. Academic literature related to the topic;
2. Interviews;
3. Questionnaire;
4. Case studies;
5. Possible statistical analysis, if enough data is available

The research questions:

1. Why construction projects are underperforming?
2. What are the main project success factors?
3. How can we improve construction project management efficiency in terms of time, cost and quality with BIM and data-driven construction?
4. What is the value of BIM and data driven construction, which is already known and being benefitted from?
5. What more can be achieved with such tools?
6. What are the pitfalls, limitations and implementation barriers of BIM and data driven construction into the industry?
7. Recommendations and suggestions for improving /increasing the data-driven construction and BIM implementation

Signature of the First Supervisor
Mika Lindholm

Author(s) Title Number of Pages Date	Diana Kustdavletova Project Success Factors and Pitfalls by Using BIM and Data-Driven Construction 108 pages (including 2 appendices) 23 December 2020
Degree	Master of Science
Degree Programme	Construction and Real Estate Management
Specialisation option	Joint Study Programme of Metropolia UAS and HTW Berlin
Supervisor(s)	1. Lic.Sc. Mika Lindholm, Principal Lecturer, Metropolia UAS 2. Prof. Dr.-Ing. Markus Kraemer, Professor, HTW Berlin

Since the development of Building Information Modeling (BIM) and various data-driven tools in the construction industry, there have been several studies related to their implementation, application, as well as established benefits. The purpose of this research is to investigate implementation barriers to the widespread adoption of BIM and data-driven tools in the construction industry. The importance of an understanding of their contribution to the success of construction projects.

The review of the existing literature has been the basis for understanding the benefits, the limitations, and implementation barriers. In answering the industry perspective on this issue, research has employed a survey strategy, which contained a web-based questionnaire, as well as semi-structured interviews.

Results obtained from the literature and survey show that barriers such as lack of standardisation, process limitations as well as barriers related to people and organisational culture are the main challenges now. It was also discovered that the main success factors for companies in the industry remain to be the golden triangle of time, cost and quality.

Although BIM and data-driven affect projects positively, especially in terms of increased collaboration between the project parties, it is, however, hard to measure their direct ability to save time or money now. It is only clear from the research findings that BIM and data-driven tools would elevate the quality of projects in the construction industry. However, to reap and secure their full benefits, all the challenges and pitfalls need to be worked on, negotiated and solved. The benefits could be accomplished and enjoyed if some changes are implemented in the industry, such as the development of common international BIM guideline and standards, training, up-skilling of industry people and support of industry clients to drive further the adoption of such technologies.

Keywords	Building Information Modeling (BIM), Data-driven construction tools, Implementation barriers, Construction project management

List of Figures

List of Tables

Table of Contents

1. Introduction

1.1 Background

The construction industry has a profound impact on the economy. It affects social and environmental aspects wherever and whenever it takes place. Therefore, the success of construction projects is critical not only for the industry itself. Notwithstanding that, the sector has an unflattering image of being inefficient, prone to constant delays, overspend, waste and many more. At the same time, the complexity and sizes of current projects are increasing, making it susceptible to extreme difficulty to control.

Nevertheless, the current pace of emerging technology and technology advancements are disrupting the industry and introducing new tools and methods to improve the industry's efficiency. Chuck Eastman has issued the first paper on the idea of using computers for drawings in building design in 1975. Building Information Modeling (BIM) has arrived at the scene of the industry. It promised to treat all the diseases of the industry. That promised included the inefficiency, delays and cost that are out of control, as well as waste that is generated by building activities.

NBIMS (2019) has described BIM as "*a digital representation of physical and functional characteristics of a facility, and it serves as a shared knowledge resource for information about a facility forming a reliable basis for decisions during its life cycle from inception onward*".

Information Technology (IT) is defined as "the study, design, development, implementation, support or management of computer-based information systems, particularly software applications and computer hardware." (Information Technology Association of America). Information in this context can be interchangeably used with the word "data." Therefore, IT manages the computers and various software to manipulate, i.e. process, protect, store and retrieve the data in a secure way (Peansupap & Walker, 2004).

To remain competitive and up to date, the construction industry needs to embrace data-driven technologies. Techopedia (2019) explains being data-driven as “a process or activity that is stimulated by data, as opposed to being driven by intuition or personal experience”. Therefore, data-driven construction is prompted by data that is collected and analysed to make objective decisions.

Currently, latest innovations such as Artificial Intelligence, Internet of Things, Virtual reality and cloud-based platforms are emerging in the industry and presenting the opportunities to gather accurate data on every aspect of a project, therefore, giving a potential improvement of the construction projects management.

BIM and all data accumulating and analysing technologies do provide tools for collaboration and creation of integrated information model. However, BIM is not only a technology, but it is also a management process that affects the cooperation between the construction parties significantly, and therefore, making construction more manageable (Information Technology Association Of America, 2019).

1.2 Problem

Notwithstanding the known attributes and abilities of such tools/processes, as well as the awareness of its tremendous importance, the implementation of them is still relatively low. Some reasons behind poor adoption of construction technologies are reported as being lack of demand from Client’s side, absence of BIM standard operation procedures, lack of BIM experts, and of course, the cost and effort of implementation. This research will try to test and search for reasons behind a low adoption of such technological tool.

1.3 Aims and Objectives

In this research study, the author aims to understand the definition of success in construction projects and find out the contribution of BIM and data-driven construction tools in such success. Digital technologies have a promising potential for the construction industry. It is said to help to produce better project management and contribute to the success of projects in terms of improved cost, time management and quality. As a result of this study, the author hopes to come up with recommendations/guideline on the utilization of BIM and data-driven tools to help produce buildings on time and within the budget, and of course, of specified quality in future. Pitfalls of their utilization will also be identified and analysed to suggest the possible ways to avoid them.

1.4 Outline Methodology

This Master Thesis reports and concludes the entire process of the undertaken research throughout the study. The first stage of the study was to select a research topic associated with the Master's Program – and it was decided to look at the technologically innovative construction processes and tools available in the industry. Consequently, the researcher conducted an exploration of the existing academic literature on the topic chosen. This review of the body of knowledge has shed light on the importance of technologically innovative solutions for the construction industry. At the same time, their limited use, as well as adoption and application.

It has been decided to focus the research on the understanding of success on construction projects and find the contribution of BIM and data-driven construction tools in such success. Moreover, since the adoption of such devices has promised to improve traditional construction approaches, the author was interested in understanding why such implementation is slow and very limited in a majority of companies across the industry.

Therefore, this research aims to achieve new insights into BIM implementation issues and understand the pitfalls of its adoption.

The process of the Research comprises of several well-defined stages. Initially, the review of background literature related to the subject is performed. Then, research data is obtained through selected methods of data collection. Such data is consequently analysed and confronted to the conclusions resulting from the literature review.

The research strategy is formed on the literature review basis, which is obtained from sources such as books, journal articles, conference proceedings, reports, etc. Such background information collection allows the researcher to explore the subject area and outline the scope of the research study. In collecting data from a broader population, a web-based questionnaire was formed out of background information and spread out. Additional more in-depth data was obtained from semi-structured interviews with construction professionals and practitioners, by following that the data collected from interviews and questionnaire has been analysed and compared with the initial information obtained from the literature.

2. Success Factors of Construction Projects

2.1 Main Characteristics of the Industry

Although the economic contribution and the role in the long-term national development of the construction industry are extensively recognized, overall, the industry is not so well understood in terms of its unique, complex nature and particular characteristics (Ofori, 2015). Temporary endeavours dominate construction projects with a strong project focus, where several independent parties come together temporarily and only if it offers financial advantages, to produce together a unique, one-off product. In addition to exclusive design and project specifications of each job that is undertaken, there usually is a very different Client on each project (Ofori, 2015).

(Vrijhoef & Koskela, 2008) claims that such characteristics of being highly fragmented also leads to low levels of efficiency and a high level of complexities and challenges. As for production in the construction industry, it can be either partly prefabricated or on-site produced. However, it is rarely repetitive and typically highly customized for individual projects. Some researchers believe that all characteristics as mentioned above of the industry are causing most of its problems and challenges (Koskela, 2000) (Nam & Tatum, 1988) (Winch, 1989) (Harland, et al., 1999) (Vrijhoef & Koskela, 2008).

(Gilge, Clay; Armstrong, Geno;, 2015) state that the risks of failure are only escalating in construction, as current construction projects grow bigger and ever complex. According to the (Armstrong, et al., 2015) in KPMG's 2015 Global Construction Survey, about 69% of construction projects fail to be completed within 10% of their budget. 75% of them also fail to be finished within 10% of their deadline. (Gilge, Clay; Armstrong, Geno;, 2015) presume that such inefficiency of the construction projects is due to the failure of the industry to embrace the technology developments and reliance on old, inefficient processes.

2.2 Success Definition for Construction Projects

The concept of project success has remained ambiguously defined in the construction industry, and until now there is no accepted universal definition of project success (Chan, et al., 2004) (Joslin & Müller, 2015). Notwithstanding that, no one can deny the importance of evaluating project success in construction, because such evaluation can help to form a basis for future jobs and the way they will be planned and managed. According to (Nguyen & Chovichien, 2013) things have to be measured to be improved.

(Parfitt & Sanvido, 1993) believe that due to the abstract and complex concept of success, it has a different meaning to different people. Therefore, it is subjective. It is especially relevant for the construction industry, where projects have numerous stakeholders, all having their diverse objectives and therefore, various opinions about the measurement of success. (Silva, et al., 2016) believe that such disagreement can be solved through developing a project participant-specific criterion. Additionally, (Chan, et al., 2004) note that the same project participant's perception of success may change from project to project, depending on the project type, size, complexity, etc. Notwithstanding that, (Parfitt & Sanvido, 1993) state that although each participant of the project differently assesses the success, the basic concept of success should be based on the overall achievement of project goals, which can be technical, financial, social, environmental etc. at the same time.

The early measurement of success in the construction industry was based on a so-called "iron triangle," which consists of time, cost and quality. Although other attributes of success were developed later, this iron triangle was and is always included in the success assessment (Atkinson, 1999) (Jugdev & Müller, 2005) (Molenaar, et al., 2013) as cited in (Luo, et al., 2016).

The measurement of time refers to the duration of time necessary to complete the project, which is typically fixed and agreed in the contract between the construction parties. Time can be measured in terms of decided construction time, or the time overrun, if necessary, the speed of construction. Time is an essential metric due to the penalties applicable in case of delays (Naoum, 1994) (Chan, 1997).

Any construction project has its contract value, which is set in the contract documents to specify how much money is needed to complete the project. The measurement of cost overrun can either be in terms of percentage net variation over the final price or cost performance index (CPI), which measures the cost efficiency of a project. The cost of a project can go up above the contract sum due to various reasons including variations, change orders, legal claims, etc. (Chan & Chan, 2001)(Heravi & Ilbeigi, 2012).

The main contractor's general obligation is to complete the works following the contract documents. The quality of work required should, therefore, be stated in the contract documents. Many contract documents refer to published standards concerning the quality required. In establishing the required standards, the contract conditions should provide for the inspection of the works to ensure that those standards are met, and state procedures for correcting defects.

According to (Khosravi & Afshari, 2011) the measurement of quality of a project is commonly defined as meeting the technical specifications of a project. Along with that, (Prabhakar, 2008) mentioned that it is the achievement of functional objectives, technical performance and specifications against which both product and process quality should be measured. Some researchers separate criteria such as quality, technical performance and functionality (Chovichien & Nguyen, 2013). (Al-Tmeemy, et al., 2011), However, (Chan, et al., 2002) thinks that they are closely related, and views project functionality as a post-construction phase measure, which is measured against the expectations of project participants when the project is delivered.

According to (Tuman, 1986) construction project success concept has considerably progressed and is now viewed beyond the traditional Iron triangle, therefore cannot be measured only in terms of cost, time and technical objectives (quality) anymore. Additionally, some researchers believe that since the role of a construction project manager goes beyond the iron triangle and includes the stakeholder relationship management, such important responsibility should also be included in the definition of success. (Lam et al. 2011; Meng et al. 2011; Ozorhon and Cinar 2015; Wong and Cheung 2005) cited in (Luo, et al., 2016). Bryde and Robinson (2005) cited in (Luo, et al., 2016) argue that while contractors normally focus on the traditional measures, such as iron triangle, clients are interested in the satisfaction of all stakeholders of a project as their measure of project success.

In addition to the classical cost, schedule and quality, (Hughes, et al., 2004) mentioned the institutionalized use of a metric related to safety on construction projects. The safety aspect on a project refers to the general conditions on site which promote the work without significant accidents and injuries Bubshait and Almohawis (1994) cited in (Chan & Chan, 2001).

Shen et al. (2000) in (Chan & Chan, 2004) view construction industry as a significant contributor to the adverse environmental impacts which affects the ecosystem in many ways through its life cycle, such as consumption of resources for building materials, waste through construction and demolition phases, energy consumption through its operational stage. In a project management context, environmental metric refers to the degree of the negative impact causing to the environment due to the execution of a project. According to (Ahadzie, et al., 2008), the environmental impact has also become an essential measure of construction project success and is used as an indicator of the environmental performance of any given project.

(Silva, et al., 2016) conclude that people who work on projects and their capabilities are critical to project success. Therefore, criteria such as Learning and Development, as well as Employee satisfaction, are increasingly being looked at closely. Given the increasing shortage of skilled workforce in the industry, such factor as the satisfaction of employees, their skill development, lessons learnt, growth and retention must be measured both during and at the end of the project and viewed as important factors affecting the future development of the construction industry. Lessons learned and experience gained through executing the project is a transferable knowledge which can be applied in future projects (Silva, et al., 2016).

Bosch-Rekveldt (2011) cited in (Luo, et al., 2016) has stated that project success should be measured from the perspective of the end-user and project results availability. The macro view offered by Lim and Mohamed (1999) cited in (Luo, et al., 2016) considers end-user satisfaction as well. End-user satisfaction is an essential measure of project success since users of facilities are the ones who work or live in those buildings, and those facilities must meet the expectations and requirements of users. Stroh (2001) cited in (Chan & Chan, 2004) believe that the satisfaction of end-users is an indicator of a successful project in the long term.

The profitability of a project is another criterion for evaluation of project success was proposed by Takim and Adnan (2008) cited in (Silva, et al., 2016) which measures the financial or commercial success of the project. It is measured in terms of revenue earned and the costs incurred. If the total income exceeds the total expenses incurred, then there is a profit. It is usually assessed at the end of the project, once the final account is settled between all the parties of a project Norris (1990) cited in (Silva, et al., 2016).

The framework for construction project success developed by (Silva, et al., 2016) as illustrated in Figure 1 below, evaluates the project success emphasizing both in the long-term perspective, as well as its short-term achievements. It is offered due to the inability to measure some of the success factors during the construction or right after its completion. More time is needed to assess the effects of the project after its completion.

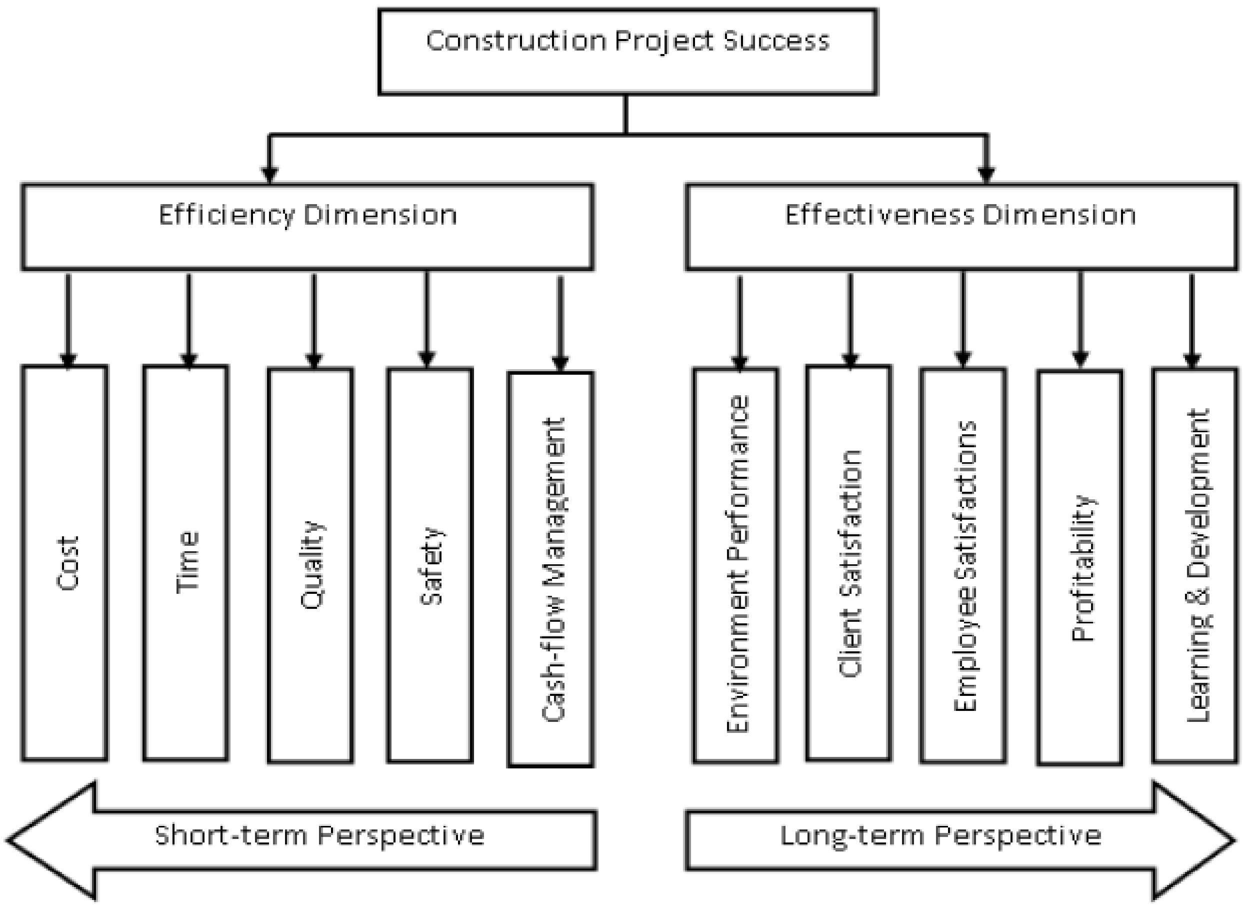

Figure 1: Framework for Construction Project Success (Silva, et al., 2016)

3. Building Information Modeling (BIM) Benefits and Pitfalls

This chapter presents the discussion, and the critique of the existing literature on Building Information Modeling, which is viewed as a technology tool, process and its application areas in terms of project management is discussed. Next, the pitfalls, challenges and implementation barriers of BIM are studied and discussed.

3.1 BIM as a Technology

According to Bryde, Broquetas & Volm (2013) cited in (Travaglini, et al., 2014), Information and Communication Technology (ICT) in Architecture, Engineering and Construction (AEC) sector has been advancing at a fast pace, due to ever-complex construction projects today which are hard to manage. And BIM is a significant shift for the industry.

BIM is valuable thanks to its dynamicity and the multi-dimensional information it contains to support the multidisciplinary and coordinated working environment among various stakeholders working on a project throughout its life cycle (Azhar, 2011). It provides an opportunity to enhance the use of Big Data and its analytics to facilitate the creation of more productive and efficient processes for the benefit of construction projects (Snyder, et al., 2018).

The increasing affordability of sensor networks and therefore, easiness of real-time dynamic data collection through Internet of Things (IoT), drones, laser scanning, Global Positioning System (GPS), Radio-frequency identification (RFID), photogrammetry, BIM can be continuously enriched with new data. It facilitates informed decisions on project costs and time management, as well as providing tools for the creation of an integrated information model. It is forecasted that the popularity and use of built-in sensors will lead eventually to the Big BIM Data (Bilal, et al., 2016).

So, what is BIM?

(NBIMS, 2019) has described BIM as "*a digital representation of physical and functional characteristics of a facility and it serves as a shared knowledge resource for information about a facility forming a reliable basis for decisions during its life cycle from inception onward*." The potential benefits of BIM are positively correlated with technology implementation to the current construction practices. Through the opportunity to construct a complete virtual prototype of a building before its actual construction, BIM offers innovative solutions to building's design and construction as well as further operation and creates a long-term value (Project Management Institute, 2016).

While some researchers focus on BIM's ability of visualization and interoperability, the others define it as a knowledge database or a 3D multidisciplinary collaboration technology. (Sacks, et al., 2018) (Sah & Cory, 2009) (Becerik-Gerber & Rice, 2010). BIM can be applied throughout the lifecycle of a building, from its planning to demolition phase. It makes the continuous flow of information from one step to another more comfortable, thus maintaining integrity and quality of the transmitted data and avoiding waste of time through unnecessary reworks or search for accurate data (Sacks, et al., 2018) (Kymmell, 2008).

The AEC industry now faces several problems such as an increase in project cost and duration and reduction in quality of the delivered outcome. It happens due to the fragmented nature of the industry and lack of standardized approach for furnishing of the information correctly. High fragmentation of construction projects is caused by a large number of stakeholders working towards a common goal, sharing and coordinating standard project information is critical. With the increased complexity of construction projects, raises the number of specialized companies involved, which increases the need for effective communication and integration thereof. Through the technology solutions that BIM brings, the industry can move forward towards an interoperable and integrated workflow of information-centric approach, from today's processes that are paper-centric.

Information-centric approach allows combining all project tasks into a process that is collaborative and coordinated, as illustrated in Figure 2 below. (Sacks, et al., 2018)

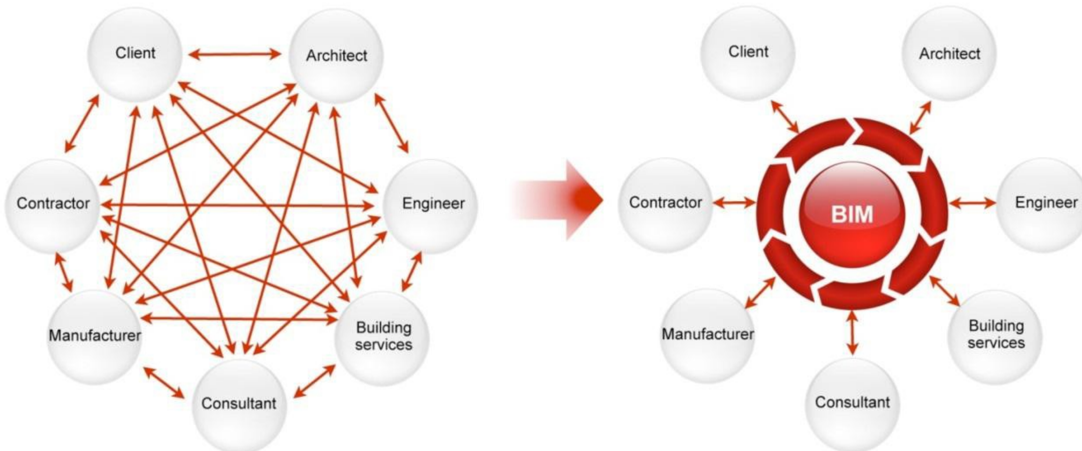

Figure 2: BIM Information Exchange (Allen Consulting Group, 2010)

Such a collaborative approach allows taking maximum advantage of computing capabilities, web communication and data aggregation into knowledge and information capture, which is equivalent to Level 3 BIM. (Sacks, et al., 2018).

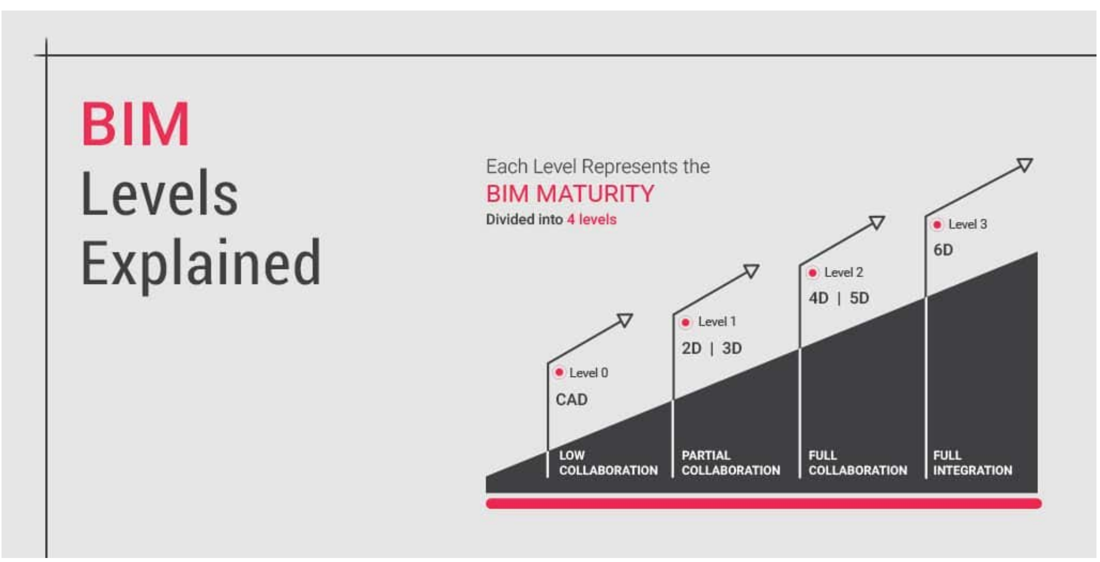

Figure 3: BIM Levels Explained (United BIM, 2019)

BIM level 3 is also called an "Open BIM", the highest of BIM Maturity, it represents a full collaboration of all building disciplines in a single project mode, which is saved in cloud storage. Such building model can be accessed and modified by all project actors without the risk of conflicting information (Sacks, et al., 2018). Figure 3 demonstrates the BIM Maturity levels.

3.2 BIM as a Project Management Tool

BIM and all data accumulating and analysing technologies do provide tools for collaboration and creation of integrated information model. However, BIM is not only a technology; it is also a management process that affects the partnership between the construction parties significantly, and therefore, making construction projects more manageable. Such benefits of BIM make it a fundamental project management tool that dramatically improves the integration and effectively reduces the project fragmentation (Information Technology Association Of America, 2019).

The main objective of BIM is managing the project information; therefore, it does not only belong to design field of the construction, but it is also a project management matter (Travaglini, et al., 2014). (NBS, 2013). As cited in (Travaglini, et al., 2014), it states that British norms on BIM, clearly call it as "managerial and informative process". SAP management software house names BIM as a "Visual PM" to emphasize the effectiveness of the BIM model for purposes of "visualization and understanding for project managers" (Cir., 2014) cited in (Travaglini, et al., 2014).

Notwithstanding the long existence of BIM in the industry and its known attributes and benefits, only recently it started being considered as a project management tool. It had happened due to the improvements that BIM has been bringing in ways construction projects are managed. Although high fragmentation of the construction projects heavily affects efficiency, BIM is believed to have an ability to solve such difficulties and aid in enhancing the integration of construction projects. Figure 4 below illustrates the difference between fragmented and integrated approaches to project management (Viig, 2018).

Recently, a lot of studies on using BIM as a project Management tool have been conducted, showing the direct and indirect benefits of using BIM as a project management tool.

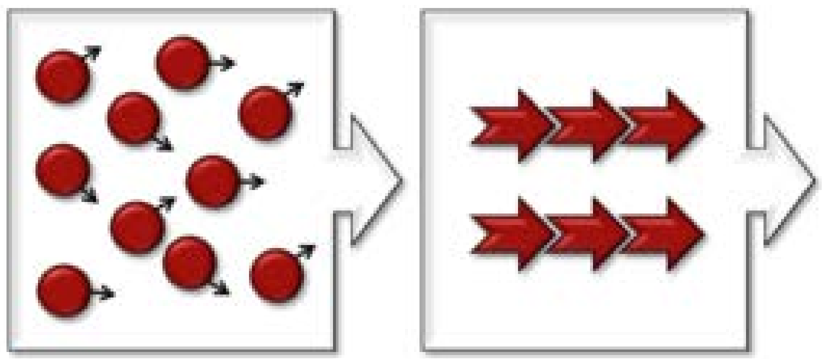

Figure 4: Fragmentation vs. Integration (Viig, 2018)

According to the (Project Management Institute, 2016), "Project Management is the application of knowledge, skills, tools and techniques to project activities to meet the project requirements". While the same components and processes apply in construction, additionally, there is the functional end product which must meet the needs of all stakeholders. Guidance on Project Management in ISO-21500 states that in achieving high project integration, all subjects and process groups (as demonstrated in Figure 5 below) should be considered throughout all phases of the project's life cycle.

Figure 5: Project subjects and process groups for Project Integration (Viig, 2018)

Use and Benefits of BIM in Project Management

Project Scope Management

Scope definition of any project starts early in its lifecycle. It is of great importance due to the more remarkable ability to influence the cost of a project in its early stages. Intensive changes in project scope at later stages will disrupt the project and result in additional charges as well as project schedule slippage. Project requirements should be fully developed and recorded in project documents such as contracts, drawings, specifications, etc. and undergo an extensive scope validation and control process. It tracks and manages potential changes; a scope baseline is created (Project Management Institute, 2016).

Figure 6 below demonstrates the advantages of BIM workflow where detailed design efforts are made earlier when the cost of making changes is still meagre, and the ability to influence the project performance is high (MagiCAD, 2020).

BIM offers a variety of tools to aid in defining and managing the scope of the project. By creating 3D visualization models of the future building, architects can give the client a better understanding and an ability to evaluate whether the design meets the project requirements in terms of its form and functionality (Project Management Institute, 2016).

A Work Breakdown Structure (WBS) is a breakdown or classification of all the work which has to be executed to accomplish the project and fulfil its deliverables. It is a foundation of effective project planning and control. BIM can also help WBS through getting a clear understanding of the composition of work tasks and deliverables of all building systems, such as architectural, structural, building MEP services, etc. Moreover, by defining the accurate scope of the project during the planning stage, conflicts between the client and contractors can be reduced (Viig, 2018).

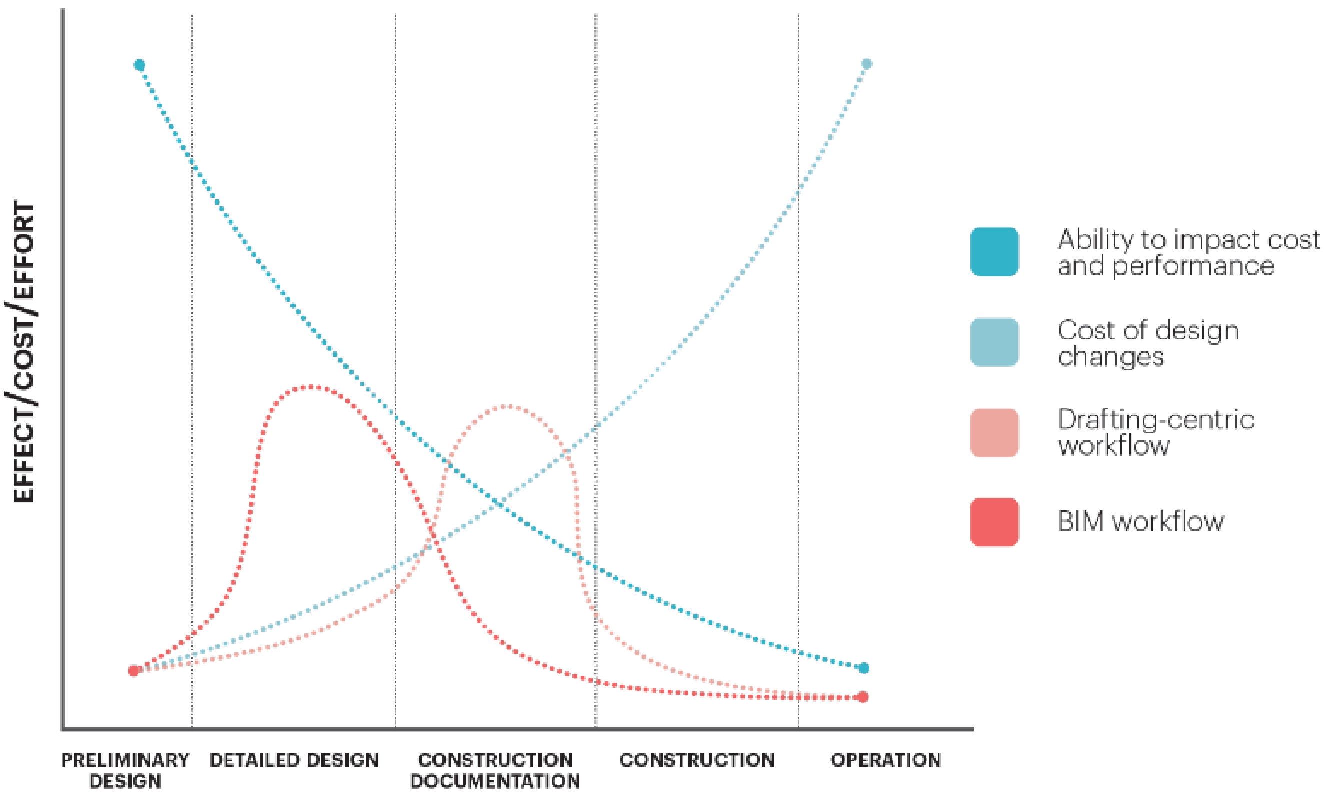

Figure 6: BIM workflow (MagiCAD, 2020)

Project Schedule Management

Construction projects are subject to pre-determined time constraints, which are set out in the contracts. Therefore, the schedule management of a project is essential for its success. With a large number of stakeholders involved, it is crucial to produce an effective schedule and ways to control it during the execution. It is also essential due to financial penalties which are imposed on late completion (Project Management Institute, 2016).

The process of planning is of crucial significance in a construction project due to the inherent uncertainties which the industry is prone to developing. During the planning stage, all work activities are defined, their sequence, duration and needed resources are estimated. Construction projects often have a large number of contracts with different project actors. Their work can either be sequenced or done simultaneously, therefore having a project schedule is essential to control and manage the timely completion and to identify the responsible party in case of delay (Project Management Institute, 2016).

With BIM, through its ability to break down the construction activities into smallest possible tasks, it is possible to develop a detailed Work Breakdown Structure, based on which then to efficiently create an accurate project schedule in either Gantt Chart or Location-Based-Scheduling method. Since, both of such scheduling types are generated based on the Critical Path Method, which can be determined correctly by BIM tools, it, therefore, minimizing uncertainties and risks of the project (Viig, 2018).

It is essential to mention the dimensions of BIM, which are a different way of linking particular kinds of data to the information model. Through adding extra dimensions such as 4D or 5D BIM, there is a potential to get a fuller understanding of the project in terms of its delivery time and cost and making better decisions (McPartland, 2017).

4D BIM is a dimension in a BIM model which comes in the form of scheduling data. Such time-related data of each construction component/system also contains visualization and accurate program information of the project, such as lead time, installation/construction time, a sequence of operation, dependencies, etc. Such information allows to develop a very accurate project program, as well as to view the construction of building components in visual representation/simulation, showing all the project stakeholders the process and logical sequence of works, therefore giving a clear understanding of project execution (McPartland, 2017). Furthermore, according to Suermann (2009) as cited in (Arayici, 2015), 'the integration of 4D into the BIM model enables monitoring during the actual construction providing critical benefit for construction planners and managers, providing a time saving of up to 19% from the planned project time". Additionally, authors note the importance of 3D and 4D in speeding up the process of obtaining building permits.

Project Cost Management

Estimating the total cost of the project is vital as the decision whether to go ahead with the project will depend on its price and whether such expenditure is in the budgeting capacity of the client. Managing and taking control of all costs of the project is also essential because the profitability of a client depends on it; it is. However, a challenging task is owing to the multiple stakeholders involved (Project Management Institute, 2016).

BIM facilitates accurate construction costs estimation even before the actual construction of a project starts, through the digitally designed BIM model. Such a model is updated and changed during the design stage. If the 5^{th} dimension or 5D (namely cost) is introduced at that stage, the model automatically extracts precise quantities and cost information. It shows the financial impact of the changes introduced to the design (Sacks, et al., 2018).

The maximum impact of BIM is produced during the design phase of a project since the ability to influence cost is the highest. The team can creatively come up with ideas and provide solutions to issues before problems become high-cost impacts to the project (Sacks, et al., 2018).

According to (McPartland, 2017), 5D dimension includes various cost information of each component of a building, such as capital costs, running costs as well as the cost of replacement or renewal.

Maintaining a high level of accuracy in the measured quantities, are generated easily from the model, rather than a drawing, therefore, creating precise cost estimates. It helps project estimators and Quantity Surveyors to provide accurate figures to the Client. All will see the economic effects of variations and change requests (Arayici, 2015).

Project Quality Management

Quality Management of construction projects involves both the product as well as process quality management, and its main aim is to fulfil the needs of the owner according to the specifications and requirements defined in a contract. Managing the quality of construction projects is critical, as it applies to features of safety, environment as well as risk management (Project Management Institute, 2016).

It validates the quality of a building project and ensures its conformance to the project requirements, quality compliance audits and technical inspections by licensed professionals are required. In cases of non-conformance, rework will be necessary, and therefore the substantial adverse effect on project schedule and costs is expected. Therefore, actions towards eliminating non-conformance or their quick identification and thus minimizing its negative impact are essential to project success (Project Management Institute, 2016).

According to (Winch, 2010), the quality management of any project has the main four components: inspection, quality assurance, quality control and total quality management. BIM has the ability to boost all four elements of quality management of a construction project through its ability to evaluate the design, increase its precision and detect clashes between different disciplines on a project. Through better coordination and communication between the various teams, the possibility of errors is reduced, and conflicts are minimized (Viig, 2018).

3.3 BIM's Ability to Contribute to Project Success

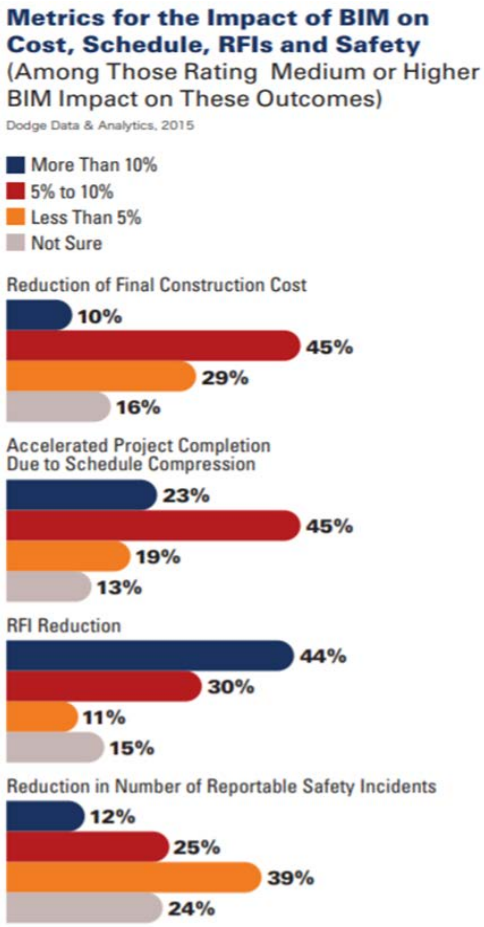

Figure 7: Metrics for the Impact of BIM on Cost, Schedule, RFIs and Safety (Jones, et al., 2015)

"The cornerstone of a solid business case for BIM is the ability to measure its positive impact on project outcomes quantitatively. Metrics demonstrating tangible and meaningful improvements will drive further implementation and investment by current users, spur those who have not yet adopted and offer everyone targets to meet and exceed on their BIM journey" (Jones, et al., 2015).

According to (Jones, et al., 2015) "a tool is only as useful as the results it produces. Therefore, BIM as a tool is only practical when it is being used to create meaningful improvements to a range of project outcomes repeatedly and positively impact all project stakeholders. The promised positive impact of BIM is to be in all stages of a project. Therefore, BIM as a tool can benefit the entire project delivery process.

The research carried out by (Jones, et al., 2015) has studied the impact of BIM on 23 complex building projects through the separate questionnaire dedicated for all stakeholders of the projects, from Clients, Architects, Engineers to Contractors. The research has focused on complex projects only as researchers believe that such schemes offer the best opportunity to experience the powerful benefits of BIM. The conclusions of the study reveal the measurable positive efficiency/productivity effect of BIM implementation. And most importantly, such developments take place not just because of software, but also thanks to the new workflow processes and extensive collaboration between the parties. It is worth noting that as a result of this study, high to very high impact ratings to given to the positive contribution of BIM to the outcomes of projects. Figure 7 demonstrates the metrics of the results of the research mentioned above.

All respondents were asked to rate or quantify the benefits in terms of construction cost savings. Then also the impact on schedule, generated by BIM usage on their projects. A little less than 90% of respondents have confirmed both the cost and time positive impacts, among which 40% of Owners report 5% of schedule compression, and 15% of them report more than 10% schedule compression. Regarding the reduction of cost, 41% of Contractors report that BIM reduced final construction cost by at least 5%, with 8% of Contractors achieving more than 10% decrease in construction costs (Jones, et al., 2015).

The survey also took account of BIM helping to reduce the quantity of RFIs, which are often an indicator of uncertainty, which can lead to changes, rework and degraded performance. 30% of respondents say from 5% to 10% reduction in RFIs, with 44% of them seeing more than 10% reduction in RFIs. In terms of Safety aspects, 12% of the respondents confirmed more than 10% less reportable incidents (Jones, et al., 2015).

Site labour productivity was also noticed to rise with BIM, as a result of increased offsite production. 67% of contractors report overall improved productivity, with 23% seeing increases of 25% or more (Jones, et al., 2015).

As a result of the study, it was found that all construction project stakeholders view collaboration as a key success factor. However, currently, most of the respondents do not try to use the early contribution of other stakeholders into the process (Jones, et al., 2015).

3.4 Pitfalls of BIM Adoption

Fullan (2007) cited in (Schia, et al., 2019) describes implementation process as “putting into practice an idea, program, or a set of activities and structures new to people attempting or expecting to change”. Specific outcomes are awaited from such a process of change, and when such implementation process fails, this happens due to incomplete initial actions or preliminary work (Noonan 2017; Senior and Swailes 2010) cited in (Schia, et al., 2019).

(Arayici, 2015) has classified BIM barriers and challenges are into five categories, as illustrated in Figure 8 below. Each type of challenge will be discussed below.

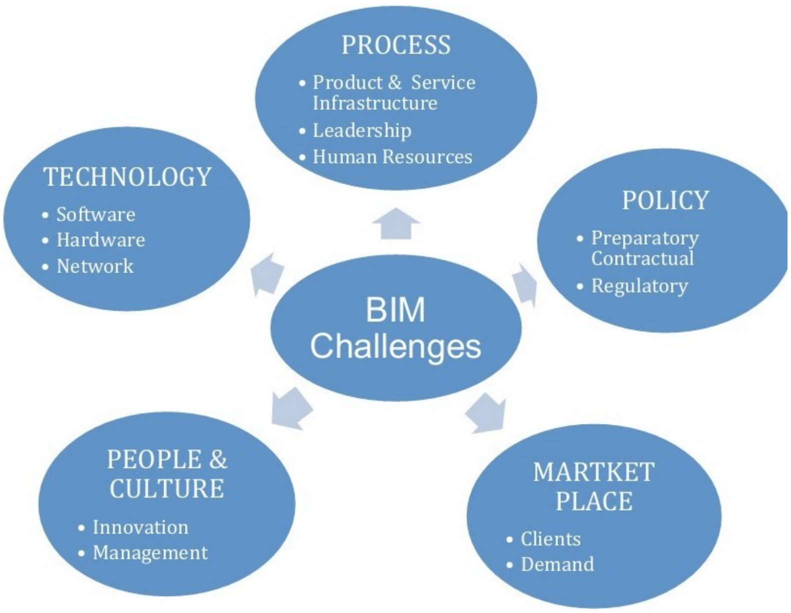

Figure 8: Challenges of BIM (Arayici, 2015)

Technological Challenges

Implementing of BIM requires a significant investment, which covers the cost of different items such as software, hardware and networking infrastructure and is considered as an obstacle for BIM adoption. Costs of software applications and licenses might not be so high, however solving potential issues such as interoperability, compatibility (file formats and versions) which are required for collaborative communication are needed to be taken into consideration (Arayici, 2015).

Formats such as IFC, IFD, COBie, etc. have been created in order to standardize the data exchange in BIM, therefore solving the issues of interoperability and data compatibility, i.e. information barrier. However, due to the various disciplines involved in construction and therefore, different software used by other companies, issues of integration and standardization of information are still open (Shang & Shen, 2014).

(Shang & Shen, 2014) in their research pointed out such technical issues as security and user interface of BIM. Matters concerning data-security is an essential point as it can adversely affect the relationship between the various stakeholders, makes the sharing of information dangerous and therefore reduces the efficiency of communication. (Alfred. 2011, Lam et al. 2010) cited in (Shang & Shen, 2014) pointed out security issues such as unauthorized access and viruses.

Further investment cost consists of high demand computer resources for running required software packages and the cost of hardware specifications that meets the BIM application requirements. Last but not least is the costs associated with networking infrastructure and internet facilities, which consists of data exchange channels and broadband speed and efficiency (Arayici, 2015).

Policy Challenges

Standards and guidelines regulate the construction industry. It lays the foundation of basic safety and quality on construction projects, as well as serving the purpose of collective understanding of construction principles between various temporary project stakeholders of a fragmented industry (Winch, 2010) (PMI, 2008) (Gustavsson et al, 2012) cited in (Hooper, 2015).

It can be argued that standards are also needed for innovation to take place. Something simple and well tested as standard solutions or routine helps to lay a foundation on top of which new innovative ideas could be realized. Therefore, in the context of BIM, standardization plays a crucial role for it to be successfully used (CIFS,2011) cited in (Hooper, 2015).

However, there is no explicit agreement or a single document which gives clear instruction on how to use BIM and how to implement it. BIM is a broadly available asset. It could be customized and flexibly applied and used for numerous purposes in the industry. As a result, there is no single official document/standard for everyone which states how to use it and for which purposes. Therefore, it is necessary to standardize the BIM process and provide a single guideline for its implementation (Cherkaoui, 2016).

According to (Ekholm et al., 2010) IT-related standards consist of 3 parts (Figure 9 below) namely: Concepts, Data Model and Process, which can be used/applied to BIM standardization as well. Concepts stand for a common language of communication, while data models are means of information exchange and processes are standard working methodology.

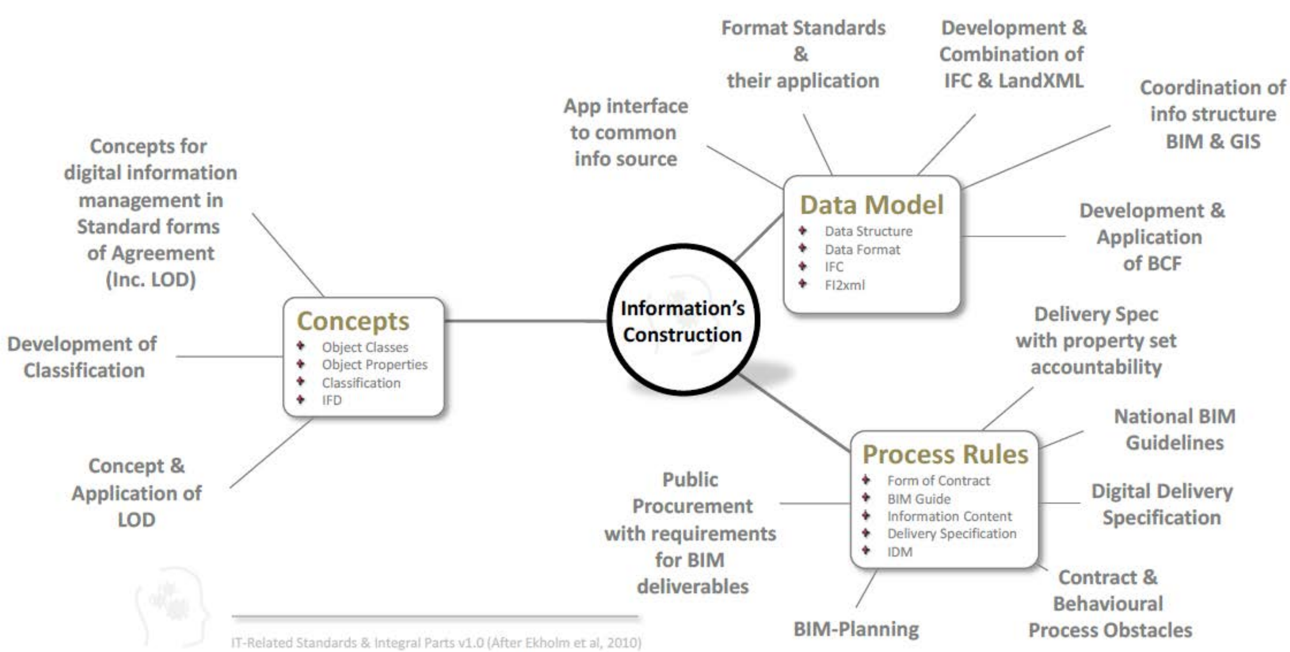

Figure 9: BIM Standardization information platform (Ekholm et al., 2010)

BIM adoption in any country or organization requires standardization efforts and adopting relevant processes. Until now, there is no particular instruction or a detailed regulatory guideline on how to use and integrate BIM into company's or countries business/regulatory practices (Gu and London. 2010) cited in (Shang & Shen, 2014). According to (Azhar, 2011), everyone is trying to develop BIM practices based on their own self-centred, fragmented standards and definitions, and this leads to inability or inefficiency in cooperating with others and unrealized benefits from BIM. The expectation of BIM is not yet being met partly because of a lack of consistent adoption of standards. Such barrier hinders the realization of expected benefits from BIM (Azhar, 2011), (Samuelson, 2010, 2011, 2012; Gustavsson et al., 2012) cited in (Hooper, 2015).

It is clear that governments have a central role in the BIM implementation process, which is done through the driving force of policies and initiatives, these are inclusive of standardization, public procurement, as well as education and development. Governments can keep the balance between the additional requirements and incentives for the industry through, on the one hand, mandating BIM for public infrastructure projects, while on the other hand, financing research and development around BIM and therefore helping companies in their efforts to implement it. However, the successful implementation of BIM requires the government to work together with the industry players and be responsive to their concerns and needs. Due to the BIM mandate for public projects, governments must invest in their own BIM capacities and understanding. For instance, in some countries, public authorities have limited knowledge of BIM advantages at operating and maintaining phase of a project, this, therefore, is a barrier from their perspective (European Commission, 2019).

Legal and Contractual Challenges

Legal and therefore, contractual issues concerning BIM implementation are the most neglected barriers, although they create the foundation for adopting BIM in the project contractual clauses. They are forecasted to be the main challenges of BIM implementation path even in future, together with the security issues (Sardroud, et al., 2018).

Legal barriers could be divided into three areas: liability, intellectual property rights and regulations. Due to multiple companies participating in the creation of the BIM model, the legal responsibilities and liabilities for mistakes remain as an unanswered question. BIM models might be copied or extracted; therefore, it is crucial to determine who has the model ownership or intellectual property rights. Provisions in contracts regarding the copyrights, license, authorized and unauthorized uses of BIM models are required. To reduce disputes and conflicts, establish a way to resolve arguments, regulations are a must. Internationally mainly working involves some standardization, a common language to work effectively together (Smith, 2014) (Ghaffarianhoseini, 2016) (Kiviniemi & Codinhoto, 2014) (Abdirad, 2015).

Contractual issues may hinder the BIM adoption due to various problems that arise when traditional work processes are translated into BIM processes. In particular, forms of contracts with BIM provisions should take into account more issues such as reliability of the information in a model, its accuracy, risks and responsibilities in a BIM product, also should specify who owns the model, how the model is maintained and generally managed (Ghaffarianhoseini, 2016), (Abdirad, 2015).

Challenges Related to People and Culture

Successful adoption of BIM requires finding as well as nurturing the right people in the industry, which is an ongoing challenge. The social context of construction is as important as its technical side, disregarding it will eventually lead to overall failure (Jacobsson & Linderoth, 2009).

People related challenges could be grouped into the following:

- Human resources

Of course, quality human resources can be the most critical component of successful BIM adoption and use. A limited number of employees with technical competency and BIM products expert knowledge can be considered as a barrier to BIM implementation. Significant time and investment are required to find real professionals, as well as training and retaining experts (Jacobsson & Linderoth, 2009).

- Conservative attitudes of professionals, resistance to change, fear of new roles and responsibilities

It is widely known that BIM is a complex combination of technological, process-driven and behavioural aspects. In contrast, the first two aspects can be dealt with efficiently. Behavioural changes are not that straightforward to tackle. BIM is about technology but more about culture, cultural change is talked about a lot. However, it is not even about being resolved. BIM is about collaboration and collaboration is in culture; it is not driven by procurement strategies and contracts (Barker, 2013).

(Yan & Damian, 2008) argue that there are sceptical views about the technology benefits, and some stakeholders may not be interested to learn about it and ways of utilizing it. Usual, habitual ways of working, working tools and processes result in resistance to change.

BIM work processes necessitate adjustment of traditional roles and responsibilities allocation on projects. While some functions and responsibilities may be replaced, others might be completely outdated and unnecessary anymore. New roles which come into view might require new sets of skills to support better coordination between various parties and maintenance of newly created integrated work models (Gu & London, 2010).

- Leading figure for management

Switching from habitual to BIM-enabled work environments requires a change in the social and cultural environment, which is difficult without a strong leadership which will guide and sustain organizational BIM vision and goals. BIM cannot work without direction, without communicating and demonstrating the company's vision, while providing resources for its implementation, it is difficult to see BIM ever being a success in action. At the moment, the industry is struggling to find individuals with both technical as well as people skills who will lead the industry for BIM implementation (Barker, 2013).

- Lack of training/awareness of BIM, Cost of training of staff

Sufficient training and up-skilling of employees in using new technology is essential for them ability to use it and make a positive contribution to the ever-changing work environment (Gu, et al., 2008), (Arayici, 2015). In the case of poor understanding of such new technology processes by the team members, the implementation of BIM will not result in success. (Arayici, et al., 2009) and (Yan & Damian, 2008) argue that the lack of training is a large barrier to BIM adoption. Companies are not very keen on investing in their staff training due to the absence of real-life examples of future financial benefits that BIM may/will present.

One of the biggest challenges which stand in the way of embracing BIM is associated with the difference in user expertise between the project participants (Figure 10 below). Varying levels of experience and competency in using BIM will affect the communication and eventually lead to further fragmentation on the project instead of driving the integration. In avoiding such risks, all project participants should be trained to have a minimum level of BIM education and understanding of its tools and deliverables. Absence of consistent level of BIM expertise will hold back effective project participation. The investment made into people's competences and knowledge will be paid off through the repetitive actions and therefore boosted productivity and familiarity with the BIM process (Viig, 2018).

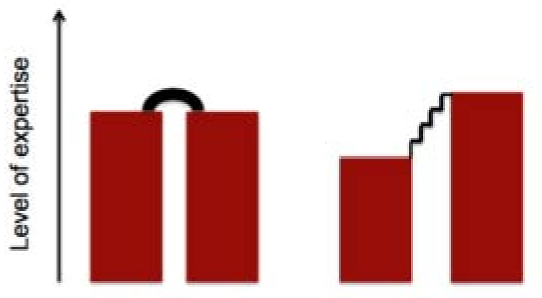

Figure 10: Different levels of expertise in using BIM between various stakeholders (Viig, 2018)

Moreover, to support such training needs, up-to-date quality training modules are necessary for both industry practitioners and students. Currently taught courses are believed to not meet the current needs of an industry due to their slow adaptation of modern design methodologies such as parametric design, for instance. Teaching staff with modern new technology experience and who adopt such latest tools knowledge in their curriculum are also deficient in number. Learners need to be trained to work in teams and appreciate the collaborative nature of BIM projects (Gu & London, 2010).

Lack of Client's Demand for BIM

(Arayici, 2015) relates the marketplace barrier to Client's demand. Client's attitude and views towards BIM could potentially be a barrier to its wide adoption. According to (Borrmann, et al., 2018) incentive to apply BIM must come from the client because due to the intense fragmentation of the industry it is up to them to specify and promote the application of BIM working methods and processes.

Findings of NBS survey 2019 state that lack of client demand for BIM is one of the most considerable barriers to its implementation. Since the private sector does not have the same mandate as public sector projects have, and there is no precondition to use BIM, there might be no incentive to adopt such technology. Therefore, if BIM is not on the client’s agenda, then it’s an obstacle to its adoption on private projects or also on smaller size projects (O’Neill, 2020).

Clients rely on professionals in the industry to procure their buildings. Therefore, such consultants and advisers must educate and inform the clients about the benefits of adopting BIM for projects, if they are to expect the clients to drive the demand for it (Waterhouse, 2020).

4. Data-Driven Construction Tools Benefits and Pitfalls

4.1 Big Data

According to the prediction of (Snyder, et al., 2018), companies in Engineering and Construction (E&C) that operate without understanding and adopting data-driven operations are likely to lose the grip of the market and remain out-of-date in the future. They view Big Data utilization and its analytics as a useful business tool, the comprehension and implementation of which is essential for the improvement of long-term business processes in E&C companies.

According to (Bilal, et al., 2016), large volumes of heterogeneous data that the construction industry already handles now, is anticipated to grow exponentially. It is due to the introduction of emerging data-driven technologies such as BIM, IoT, Robotics, Drones, Laser Scanners, Cloud-based platforms, GPS, Augmented reality, etc. Figure 11 below portrays the future outlook of a construction industry according to the World Economic Forum.

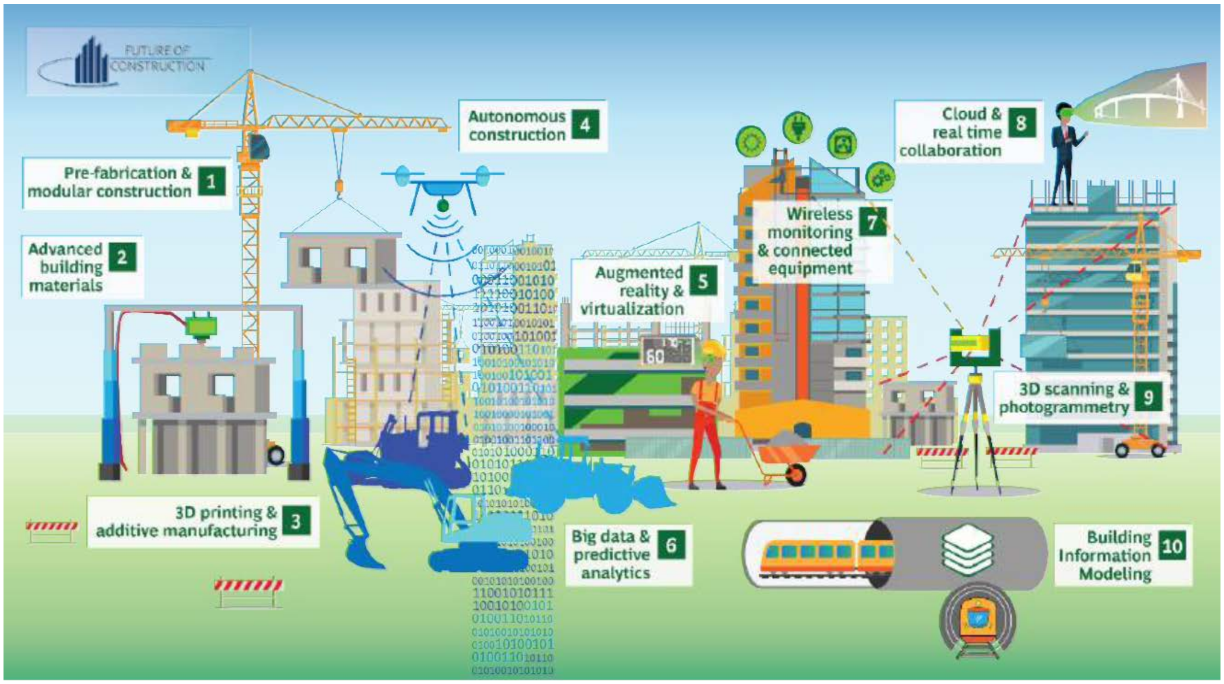

Figure 11: Future of Construction, World Economic Forum, Boston Consulting Group (Buehler, et al., 2018)

Leading analytical company SAS has defined Big Data as a “data that is so large, fast or complex that it’s difficult or impossible to process using traditional methods.” Widely adopted definition of Big Data as formulated by Gartner analyst named Laney Doug is based on three Vs, namely: Volume, Velocity and Variety. According to this description, Big Data could be collected in large volumes (terabytes, petabytes) from an extensive range of sources, at an extraordinary speed or even real-time, as well as in all sorts of available formats (text, audio, video, graphs, etc.). However, it is not the volume of the data that is the key, but the ability to analyse, uncover patterns, correlations and use this data for forecasting and better-informed business decisions, that is to create the fourth “V” which in this case stands for Value, as illustrated in Figure 12 below. (SAS Analytics Software & Solutions, 2020) (Zhu, et al., 2016) (Lu, et al., 2019).

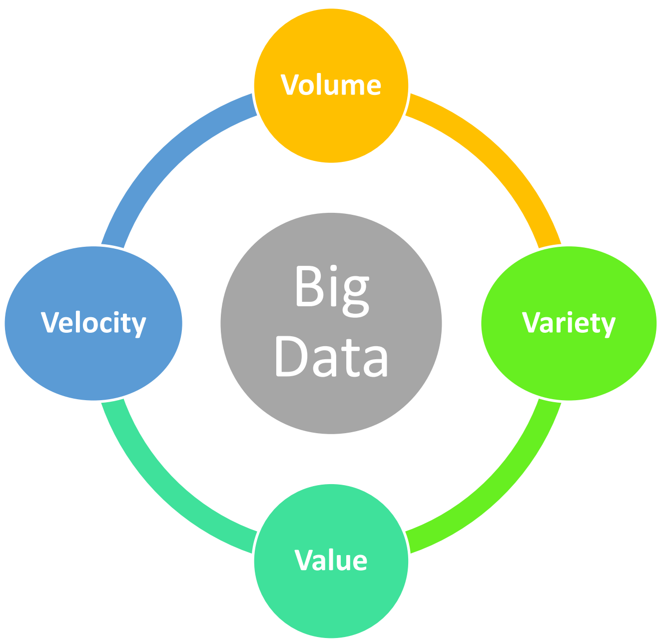

Figure 12: Big DATA 4 Vs. (Lu, et al., 2019)

(Bilal, et al., 2016) has offered to differentiate between 2 aspects of Big Data to understand it: Big Data Engineering (BDE) and Big Data Analysis (BDA). BDE area involves the storing of relevant data, as well as activities for analysis. At the same time, BDA is associated with extracting the critical knowledge/insights to facilitate the decision-making and is connected with principles, processes and techniques to comprehend Big Data. BDE gives infrastructure to support BDA; in contrast, BDA looks for valuable patterns in data (Provost & Fawcett, 2013).

According to Simon (1982) cited in (Lu, et al., 2019) decision making by humans is limited by their human mind's cognitive capabilities to process large amounts of information coming at high speed. According to Padhy (2013) cited in (Lu, et al., 2019), decision traditional data management tools have also been proven unable to process and analyse large volumes of data. Therefore, advanced information and communication technologies must be involved. Due to the velocity of incoming data, the time available for decision making is also limited. Small Data, as opposed to Big Data, is based on traditional methods of data collection, which makes it prone to bias. On the other hand, Big Data can improve the quality of data through its variety and volume, making it possible to see different perspectives, patterns, correlations etc. by the analytics of such data (Lu, et al., 2019).

(Techopedia, 2020) explains being data-driven as "a process or activity that is stimulated by data, as opposed to being driven by intuition or personal experience." Nevertheless, Big Data is not valuable just on its own, to enable the greater comprehension and its better use, innovative forms of information processing are needed. As already mentioned above, existing traditional tools are unable to handle or process that amount of Data (Gartner, 2014) (Akbar 2017) cited in (Ismail, et al., 2018). Therefore, data-driven construction is prompted by data that is collected and analysed to make objective decisions.

Notwithstanding the opportunities presented by using Big Data analytics in E&C, to harvest them, solving some challenges is required. (Snyder, et al., 2018) states that, first of all, a clear understanding of the organizations end goals and vision is necessary. To reach the vision of the company, the strategy and correct planning is needed, therefore in a magnitude of information available, understanding of which data is useful is essential. To build up such vital new processes in a company will require right procedures, tools and of course, the right people (Snyder, et al., 2018).

Big Data and the Construction Industry

In E&C industry, there is a significant number of sources for data, that is generated by various stakeholders in various phases of construction projects. Such flow of data comprises of drawings, financial data, photos, GPS, sensors, RFID, wearables, emails, various reports etc. Therefore, 3Vs are undoubtedly apparent in E&C Industry as illustrated in Figure 13 below (Shrestha (2013) cited in (Ismail, et al., 2018)). However, according to (Hill, 2017) due to the difficulty to manage and process such a hefty amount of data, currently, about 96% of all captured data in E&C goes unused. Missed Big Data opportunities in E&C industry are illustrated in Figure 14.

Characteristics	Contributors	Examples
Volume	Large volume of data from different sources	Design data, cost data, financial data, contractual data, Enterprise Resource Planning (ERP) system, etc
Variety	Diversity in the content format	DWG (drawing), DXF (drawing exchange format), DGN (design), RVT (revit), ifcXML, ifcOWL, DOC/XLS/PPT (Microsoft format), RM/MPG (videos), JPEG (images)
Velocity	Dynamic nature of data sources	Sensors, RFIDs, Building Management System (BMS)

Figure 13: BIG Data in the Construction Industry (Ismail, et al., 2018)

(Thomas, et al., 2018) in their report “Construction Disconnected” have surveyed globally around 600 construction leaders to discover the activities because of which construction teams are losing their valuable time. It was found that on average 35% of their weekly work hours, team members spent on non-optimal activities, such as looking for project data - 13.4%, conflict resolution – 11.6% and dealing with mistakes and rework - 9.6%. Majority of respondents have mentioned that poor communication among stakeholders and inability to access accurate project data are the main factors for spending extra time on non-optimal tasks. Inadequate and ineffective communication between the project parties, as well as inability to access correct data will inevitably lead to rework as well as financial consequences; such loss was equal globally to about 280 billion USD in 2018. (Thomas, et al., 2018)

Figure 14: Missed Big Data opportunities in E&C industry (Snyder, et al., 2018)

Therefore, construction companies need to concentrate on adopting the technology that will allow access to accurate, up-to-date data and easy communication. Capturing more accurate data and retaining it through the lifespan of a building is believed to not only reduce a building lifecycle operation costs, but also present improvement in contractor/owner relationship (Thomas, et al., 2018).

Big Data is believed to have a significant influence on construction project management and is considered as a useful tool that guarantees project success, all due to the data-dependent characteristics of the industry (Ismail, et al., 2018). (Bilal, et al., 2016) believe that Big Data adoption in the construction industry could be increased and pushed to the next level through the triggering constituents and trends such as BIM, Cloud, IoT, Drones, etc.

4.2 Data-Driven Construction Tools and Their Benefits

The following section of the Literature Review will discuss the triggering elements of Big Data – data-driven tools in the construction industry, as illustrated in Figure 15 below.

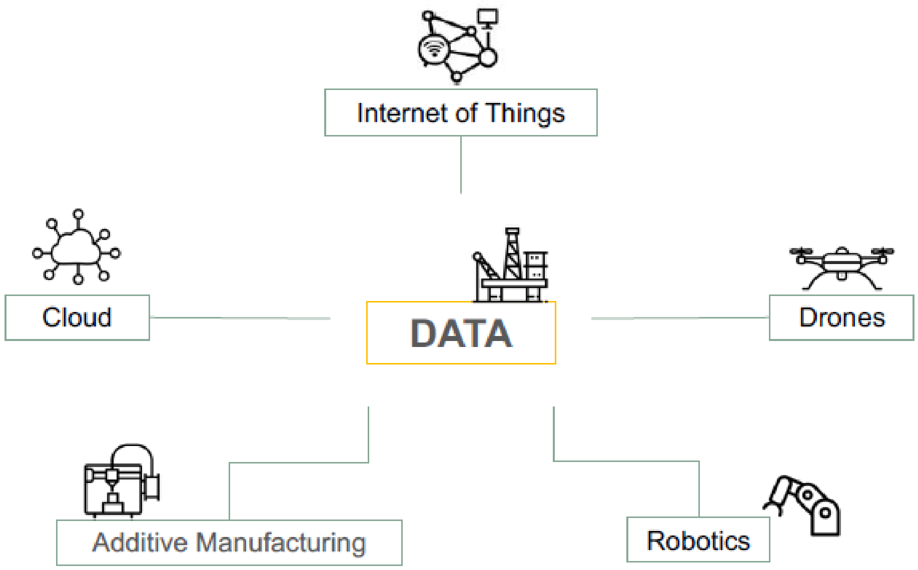

Figure 15: Triggering Elements of Big Data

Internet of Things (IoT)

The Internet of Things (IoT) is believed to be the central technology that triggers Big Data and is claimed to be co-dependent with the Big Data trend (Bilal, et al., 2016). It is defined as a sensor technology that enables the systematic capture, accumulation and harnessing of data; it is a system of Internet-connected devices that gather and transfer data through installed sensors. With IoT, it is possible to measure, monitor, and manage the condition of practically everything in the environment in near-real or real-time time (Rajagopalan , et al., 2019).

IoT is a non-standard computing device, which can wirelessly connect to any network and transmit data. The main benefit of the IoT is its ability to connect everyday non-internet enabled objects to the internet through embedded sensors, meters, actuators. With IoT technology in non-internet devices, it is possible to create communication between the devices, monitor and control them remotely (Rouse, 2018).

IoT produces a large quantity of unstructured data in a real-time. However, such data is of limited value. Analytics of such significant amounts of data can only be performed by AI, which adds more significance and use of such data. It can be argued that the IoT is a facilitator of AI (Kranz, 2017).

Cloud Computing

According to the (Dryfhout & Hewer, 2019), cloud computing is “the practice of using a network of remote servers hosted on the Internet to store, manage, and process data, rather than a local server or a personal computer”. In other words, it is a computing service that is provided on-demand, over the internet, typically for storing data, networking, processing power, artificial intelligence or even standard office applications. Currently, some software vendors are offering their applications via cloud-based on a subscription model. Cloud computing is beneficial for companies who want to avoid expensively and difficulties of owning and maintaining their own IT infrastructure and data centres, and instead to rent access to applications, storage servers through secure service providers and pay only for resources consumed (Ranger, 2018).

(Qubole, 2017) cited in (Ismail, et al., 2018) claims that the development of cloud technology has contributed towards the evolution of Big Data. Moreover (Ferkoun, 2014) cited in (Ismail, et al., 2018) supports the idea of cloud computing and big data being a perfect combination that creates value through the extended infrastructure to support Bid Data Analytics.

Robotics

Inefficiencies, low productivity and quality issues in construction have the potential to be addressed and solved through using automated systems and robotics, which have been effectively proved in other industries. However, the rate of their adoption is very low in the construction industry. Since construction requires a lot of labour-intensive activities, issues such as low productivity, low quality, injuries from dangerous tasks, as well as high labour costs are inherent (Davila Delgado, et al., 2019). (Bock, 2014) argues that conventional construction methods have reached their limits, have to surrender and give way to new technologies.

(Jayaraj & Divakar, 2018) claims that the construction industry is the most unorganized and labour intensive. Although robots are already being used on some construction sites for certain tasks, they are not utilised to their full potentials. AI can reduce required workforce on-site, reducing construction time and cost, improving quality, safety and working conditions. Major advancements, according to (Jayaraj & Divakar, 2018) are seen in robotic control, sensing, vision, localization, mapping, and planning modules that can ensure an accurate and precise job.

(Bogue, 2018) predicts a dynamic role for robotics in the future of the construction industry, claiming that such technological advances as BIM, sensing technologies, and artificial intelligence will push the robotics adoption further.

There are different types of robotics and automated systems in the construction industry, due to technological advancements, the lines between those types are updated continuously and blurred.

The categorisation of those types as presented by (Bock, 2014), can be divided into four categories, as demonstrated in Table 1 below.

Table 1: Examples of robotic, automated and autonomous systems in the construction industry. Adapted from (Davila Delgado et al., 2019)

	Off-site prefabrication systems	On-site automated and robotic systems	Drones and autonomous vehicles	Exoskeletons
Description	Developed to increase the quality of building components – production off-site, in an automated manner	Automated and robotic systems used directly on the construction site	Terrestrial, aerial or nautical vehicles (autonomous or piloted remotely) used for inspection, surveying, monitoring and maintenance	Wearable devices that work together with the user as opposed to a robot which performs the task autonomously
Types and use-cases	• Building component manufacturing (BCM) • Large-scale prefabrication (LSP) • Additive manufacturing (3D printing)	• Single task construction robots (STCRs) for bricklaying, steel-truss assembly, steel welding, façade installation, wall painting, concrete laying, etc. • Robotic on-site factories • Swarms and robots for building component assembly	• Access to extreme and dangerous environments • Automated drilling, excavation and earthmoving	• Improve workers productivity: lift heavy loads, reduce fatigue, and facilitate the use of tools in awkward positions. • Reduce injuries

Drones

According to (Liu, et al., 2014) as cited in (Arslan, et al., 2019), an unmanned aerial vehicle (UAV) or unmanned aerial systems (UAS) is an aircraft system that is controlled autonomously or by a pilot on the ground. It is also known as a drone or remotely piloted vehicle (Siebert & Teizer, 2014)**.** This innovative technology has several useful functions that can benefit the construction industry; for instance, it can perform data collection and live transfer of such data for further processing. Tools such as cameras, radars, infrared, communication devices can be mounted on UAS. It can also be linked to Wi-Fi networks and GPS and be controlled by smartphone devices (Mosly, 2017) (Irizarry & Costa, 2016).

It is said that the development and wide use of UASs will benefit construction during the execution of its projects through providing opportunities to save time and money due to the simplified and improved monitoring process (Herrmann, 2018) cited in (Arslan, et al., 2019). Notwithstanding the advantages of such technology, the industry is slow to adopt it (Holt, et al., 2015) cited in (Arslan, et al., 2019). Publications on UAS in the construction industry are concentrated around three areas such as quality control, health and safety as well as on-site data collection. Table 2 below illustrates several publications for each of the three areas of application of UASs.

Table 2: Evaluation of Drone applications. Adapted from (Arslan et al., 2019)

Quality Control	Health and safety	On-site data collection
• Visual inspection and damage detection increased possibility of discovering the unfound problem on construction projects. • UAV application for the building inspection and collecting the data at difficult to reach areas, mitigating the risk of adverse safety conditions. • A framework for the automated monitoring process. • Using UAVs and BIM to compare as-planned and as-built situation of buildings. • Developing an automatic imaging network design which uses UAVs to improve the efficiency and accuracy of the automated construction progress monitoring.	• Monitoring and controlling on-site construction activities, improving safety operations or monitor potential hazardous situations, risks for workers. • UAV assisted visual monitoring method to prevent struck-by accidents in construction projects. • A safety inspection method that integrates UAV and BIM.	• Combined use of BIM and UAV technologies in order to achieve efficient and accurate as-built data from a construction site. This is a vital aspect of good construction management performance. • Enabling UAVs to gather data in a time-efficient manner in construction activities. • Generate a panorama of a construction site by using UAVs. • Using UAVs to create a new method which automatically retrieves photo-worthy frames containing construction-related contents in order to have the data from construction sites. Collection of Data from construction site related to: 1. Structural damage assessment 2. Land Surveying 3. Earthmoving operations 4. Material Tracking 5. Vehicle detection and tracking 6. Human performance

3D Printing

According to Labonnote et al., (2016) as cited in (El-Sayegh, et al., 2020), 3D printing can be defined as “the process of making an object from a three-dimensional model by adding thin layers of material on top of each other”. Even though some use 3D printing term interchangeable with the term Additive Manufacturing (AM), these terms are not the same. AM refers to a more all-inclusive period, defined by the International Organization for Standardization (ISO) as “the process of joining materials to make objects from 3D model data, usually layer upon layer” (El-Sayegh, et al., 2020).

The most common methods for 3D printing used in the construction industry are the gantry system (printer with a nozzle which moves in three axes – X, Y, Z) as well as the articulated robot system (Labonnote et al., (2016) as cited in (El-Sayegh, et al., 2020). Cementitious materials, polymer materials, and metallic materials are found to be the most widely used materials for 3D printing (Camacho et al., 2018) cited in (El-Sayegh, et al., 2020).

3D printing is considered as a promising new technology with potential benefits in both constructability and sustainability. It has the potential ability to save time by faster construction, lowering the cost of construction, increasing productivity, while offering more space for architectural geometry. From the sustainability point of view, such a process can reduce the amount of waste generated by tradition methods, use of recycled materials, raw earth materials and geopolymers. Furthermore, 3D printing use results in safer working conditions for construction workers, as well as reduction of required numbers of site personnel (Ghaffar S et al., 2018) (Wu P. et al., 2016) cited in (El-Sayegh, et al., 2020).

Artificial Intelligence

Artificial Intelligence (AI) can be defined as “a wide-ranging branch of computer science concerned with building smart machines capable of performing tasks that typically require human intelligence (Sharma, 2017). Oxford Reference (2020) describes such tasks “as visual perception, speech recognition, decision-making, and translation between languages”.

Knowledge Engineering, as well as Machine Learning (ML), are central parts of AI. Since imitation of human behaviour by smart machines requires them to have knowledge or information about the world as well as the ability to acquire a new report, the primary purpose of ML continuously is to let machines learn automatically and independently of human involvement. ML, therefore, provides such ability to AI, to acquire knowledge and learn from experience without being explicitly programmed (Expert System, 2019).

According to (Clavero, 2018), AI, as opposed to human intelligence, is not limited by time nor space for its information processing abilities. Apart from the ability to process large amounts of data quickly and accurately, it is also proficient in analysing it and creating trends and patterns. Bolton (2018) (Ballard and Howell 1998) cited in (Schia, et al., 2019), describes the lean benefits of AI for business. It was minimizing waste through reduced human factor errors, maximizing value through increased efficiency of work processes achieved by automation of repetitive tasks and ability of people to focus on value-adding actions.

Although the implementation of AI in the construction industry is at its starting phase, there are a lot of potential benefits that it can offer to tackle inherent project challenges. Table 3 below illustrates the impacts that AI can have on construction projects through ML, pattern recognition and automation abilities (Schia, et al., 2019).

Table 3: Future application of Artificial Intelligence (Schia et al., 2019)

Categories of AI	Application	Impact
Machine learning	Scheduling	Analysis of a large amount of data based on historical figures and human input. Makes it possible to evaluate millions of scheduling options that take humans exponentially longer to accomplish
Pattern recognition	Health, Safety and Environment	Predict/early detection of dangerous situations by using machine learning algorithms in combination with pattern recognition
Pattern recognition	Storing space	A digital map that continuously shows the site and where it is possible to store materials or machines. Will increase the predictability and efficiency on site
Pattern recognition	Detection of unregistered people	Using pattern recognition to detect people and find those who are not registered at the construction site. Will increase the safety and possibility of larceny and criminal damage
Automation	Robots executing dangerous work	For example, work in the height, such as fire protection of steel beams. Will improve the safety of humans
Automation	Self-driving construction machinery	The use of robots and self-driving construction machinery will change work flow
Automation	Quality assure work	Robots that drives around the construction site scanning the site situation and compare it with the BIM. This technology may save hundreds of hours spent of quality assuring work, both considering the main- and subcontractors

4.3 Pitfalls of Big Data and Data-Driven Construction Tools

Although Big Data presents new opportunities for the benefit of the industry, there are still many unresolved challenges and concerns. First of all, the security of generated data and its protection is a significant concern. Appropriate access control and intrusion prevention measures are to be adopted to protect the databases (Bilal, et al., 2016).

Quality of generated data is another challenge. High-value analytics can be problematic if the information is of low non-standardized quality. The results of such data can be misleading and can cause unnecessary problems (Bilal, et al., 2016).

The financial side of introducing Big Data requires substantial investment from construction companies who already run their businesses on low-profit margins. Companies will be required to not only to run and maintain large data centres with networking infrastructure but also to employ skilled IT staff and purchase licenses to run relevant software. Internet connectivity for Big Data applications is also required to transmit and monitor project activities in real-time. Therefore, investments to appropriate infrastructure will be expected (Bilal, et al., 2016).

Factors Limiting the Adoption of Robotics in the Industry

(Davila Delgado, et al., 2019) have identified several factors which affect the adoption of robotics. Those factors are discussed below:

Economic Factors

Contractor-Side Economic Factors

In summary of their research, (Davila Delgado, et al., 2019) have come to the opinion that the most significant barrier towards robotics adoption in the construction industry is an economic factor, especially the ones represented from contractors' side. Due to the industry's high-risk features, as well as low-profit margins, implementing new technology developments and therefore investing capital into it, is not considered feasible by contractor companies. Although high initial investment costs could be justified due to expensive labour costs and raised productivity, few contractor companies can assign resources for such new technologies. Additionally, the authors found out that contractor companies do have easy access to labour at the moment. Also, the need for productivity improvement is not so strong from the contractors' side (although this usually is different from the Client's side). Both reasons being a further disincentive to robotic technologies embracement.

Client-Side Economic Factors

Clients and their demands always play a significant role is the adoption of new technologies on their projects. Because governments happen to be the main clients of the construction industry, they undoubtedly affect the industry a lot. For instance, the decreased current public budgets and therefore reduced spending for infrastructure projects in industrialized countries, lead to tendering practices which prioritize the lowest possible prices. Thus, putting pressure on tenderers to offer the most competitive offer, and thereby further reducing the possibility to innovate (Davila Delgado, et al., 2019).

Technical Limitations of Robotic Technologies

According to (Davila Delgado, et al., 2019), the industry doubts its readiness for robotics adoption due to technical issues. The prevailing of a weak innovation culture and high complexity of construction tasks require robotic solutions. They are tailor-made or customized and flexible enough to be used/usable in complex construction site conditions. Every project and project site conditions are different. Moreover, (Buchli, et al., 2018) adds that “there are still many technical challenges including a lack of functional integration, ineffective localization, planning, and guiding algorithms, inadequate sensor technology, insufficient robot intelligence, and the difficulty of robots to operate on complex and uncontrolled environments”. Providing that every project has its client, whether investments put in robotics can be fully used with different clients in future is also under question.

Weak Business Case

Lack of use and therefore, lack of evidence of the beneficial use of robotic technologies is also a massive obstacle. According to (Davila Delgado, et al., 2019) there is not enough evidence of robotics adoption being able to reduce the cost of delivering projects or having a high return on investment. Although 50% saving of the time is promised for specific construction tasks, it is said that time and money spent on safety training are not considered. Although robots can reduce the costs related to hiring labour, at the same time there should be a significant amount of money put into its adoption, such as the robots themselves, software, skilled engineers and programmers, training, etc. (Davila Delgado, et al., 2019).

Factors limiting the Adoption of 3D Printing in the Industry

(El-Sayegh, et al., 2020) point out seven groups of challenges associated with the 3D printing in the construction industry. As illustrated in Table 4 below, 3D printing has quite many challenges and barriers to its widespread adoption in the industry. Material-related challenges are associated with the need for new materials suitable for construction, which have to be of the right consistency, able to be pumped, printed and able to hold a load of the structure without deformation (El-Sayegh, et al., 2020).

Table 4 - Challenges of 3D printing in construction (El-Sayegh, et al., 2020)

No.	Challenges related to:	Description
1	Material	Printability, Buildability, Open time
2	3D printer	Scalability, Directional dependency, Geometrical limitations
3	Software related	Cybersecurity, Interoperability, Suitability of the digital model for printing
4	Architecture & Design	Exclusion of building services, Structural integrity, New design principles
5	Construction Management	Cost estimation, Construction site setup, Construction scheduling
6	Regulations & Liability	Lack of codes regulations, Liability issues
7	Stakeholders	Scepticism of about the potential of 3D printing, Less demand for workers, New skills for construction workers

The size of the design is constrained by the chamber volume of the 3D printer. Currently, 3D printing is not suitable for larger-scale projects. There are also geometrical limitations and directional dependencies, which set certain restrictions on the design possibilities (El-Sayegh, et al., 2020).

Software-related challenges are associated with cybersecurity, interoperability of software used for design and printing, as well as digital model suitability. 3D models and their safe storage and transfer between the parties could potentially be under cybersecurity threat, and safe working conditions are to be ensured. Making sure that digital model is suitable for 3D printing requires time and careful verification process, at the same time all disciplines involved should work together to ensure interoperability of various application and software needed for the printing procedure (El-Sayegh, et al., 2020).

Cost is another challenge since 3D printing is an emerging technology, not readily available, it involves high initial price required to purchase the 3D printer, as well as the cost of maintaining it. Transportation cost or on-site fabrication, expenses to set up the equipment, creation of a controlled environment for the future quality of work and finally the cost of new concrete material suitable for the construction printing all add up to the substantial amount of investment (El-Sayegh, et al., 2020).

Absence of set regulations for 3D printing in the construction industry is another challenge, since conforming to all construction codes can be a problem. There is a need for characterization of materials for 3D printing. There is a need for standardized and clarified construction practices and processes with the integration of such into the existing building codes and regulations. Moreover, a legal framework needs to be developed to solve open issues such as accountability and liability in case of problems with 3D printed objects (El-Sayegh, et al., 2020).

Lack of knowledge and therefore, sceptical views about the benefits of 3D printing from clients, as well as other parties of construction projects is another substantial challenge to its widespread use. The negative social effect of 3D printing practice due to the reduced number of construction labour is also a possibility. However, it is also an opportunity to develop new skills for construction workers. Such skills and knowledge might not be readily available on project sites (El-Sayegh, et al., 2020).

Factors Limiting the Adoption of Artificial Intelligence (AI) in the Industry

Despite the ability of AI to solve various problems of the industry, its implementation still has barriers on its way. There are several obstacles that the industry still has to overcome. First of all, resistance to change is a challenge associated with AI implementation. Since AI has been long associated with unknown territory, it is still subject to various questions and scepticism. Lack of proven business cases and success stories naturally results in mistrust and resistance (Koutsogiannis, 2019) (CONEXPO-CON/AGG, 2020).

Lack of knowledge about AI application results in job security fears, some people might believe that AI will be removing the need for humans and consequently result in a reduced number of jobs available. However, it must be understood that the emergence of AI in construction will, on the contrary, open opportunities for people to leave repetitive mundane tasks. They will be able to concentrate on skilled expert tasks, thus supplementing humans rather than substituting them (Koutsogiannis, 2019) (CONEXPO-CON/AGG, 2020).

Security has also been a significant concern from the perspective of IT. Such as protection of data and prevention of intrusion from outside. Lack of security standards and challenges such as interoperability are also challenges associated with AI adoption in the industry (Koutsogiannis, 2019) (CONEXPO-CON/AGG, 2020).

5. Use of BIM and Data-Driven Construction in Companies

5.1 Research Strategy for this Thesis

Before discussing the research findings, it is necessary to define the research and explain the strategy adopted for this piece of work. Oxford English Dictionary has defined the word "research" as a "systematic investigation into and study of materials and sources to establish facts and reach new conclusions." Research is a vital part of academic activities, as well as business interests. Therefore, it has a different meaning for different people. Research can also be defined as a study or inquiry conducted in a scientific manner or a method for data collection and analysis. It is a contribution to the existing knowledge and a learning process (Naoum, 2013) (Creswell, 2003) (Fellows & Liu, 2003).

(Saunders, et al., 2009) describe the process of effective research methodology development through their research "onion" diagram, Figure 16 below, where each layer of the onion illustrates a more detailed stage of the research process that the researcher must pass through to formulate the centre of the research "onion", an effective methodology.

Choice of the proper research strategy is crucial for answering research questions and achieving research objectives generally and must be carefully considered. For this Thesis, a mixed-method research approach was chosen. The author feels that such a system is suitable and allows for greater insight into the research area.

The objective of mixed research method is to answer the research question by blending the method views, data collection techniques and analysis of quantitative and qualitative methods together (Johnson, et al., 2007) (Creswell, 2003) (Borrego, et al., 2009). The main benefit of this increasingly used method is a diversity of perspectives and capability of combining the strengths of both quantitative and qualitative methods, which cannot be reached by using just one way (Johnson & Onwuegbuzie, 2004).

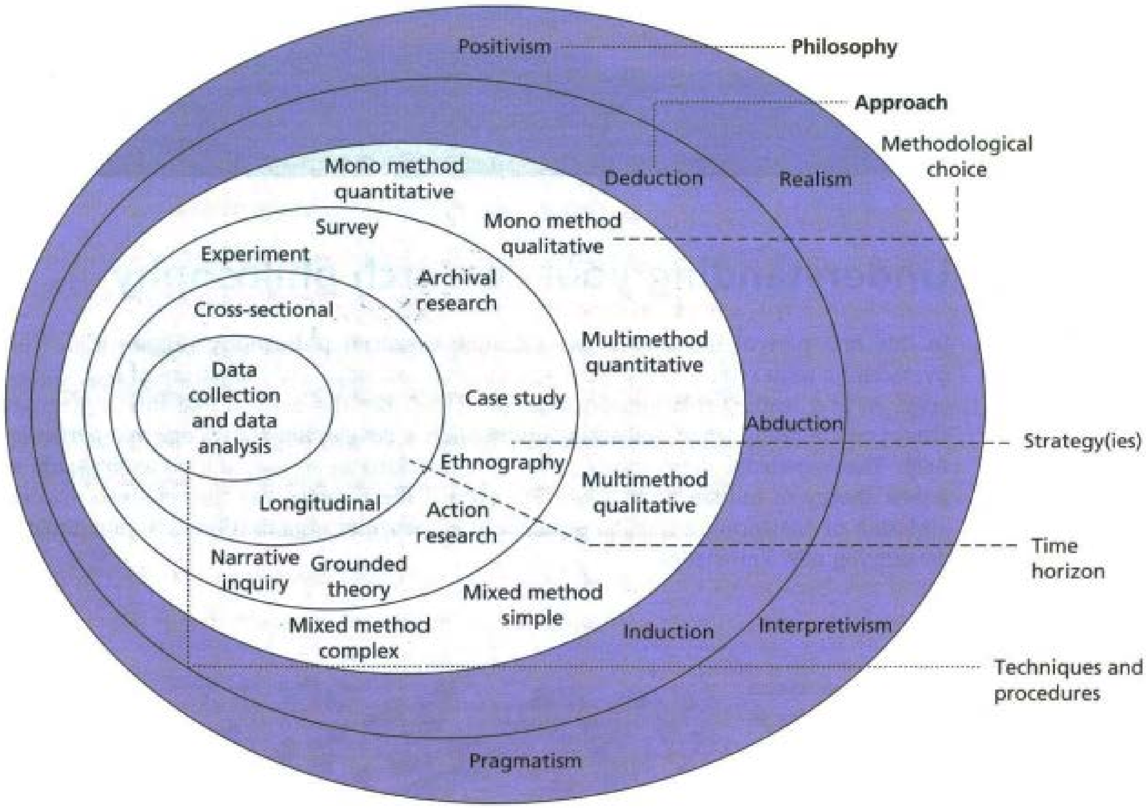

Figure 16: The Research "Onion" (Saunders et al., 2009)

(Jogulu & Pansiri, 2011) the claim that adoption of a mixed method of research allows the researcher to understand the phenomena through deep insights and subjective interpretations, at the same time minimizing the over-dependence on statistical data that is common for quantitative research method. Together such methods create a comprehensive way of investigating the occurrences through multiple paradigms.

On the other hand, such methods of research are believed to be unsuited due to different research cultures and methodologies. Also, more resources such as time are needed when such process is selected. It is due to the need to integrate the findings of each of the research methods (Scott & Briggs, 2009) (Seale, 2002) (Brannen, 2005). Table 5 illustrates the selected research strategy and techniques.

Table 5: Research strategy and selected research methods

Research Steps	**Research Objectives**	**Research Questions**	**Research Method**
Step 1	To investigate Big Data and its uses in the Construction industry	• What is Big Data? • How can it be utilized in the Construction industry?	Literature Review
Step 2	To investigate the main concepts of BIM	• What is BIM? • What is the BIM uses for construction project management? • What are the benefits of BIM for construction projects	Literature Review
Step 3	Data-driven Construction tools and their use	• What are they and how they are/can be used for construction projects?	Literature Review/ Survey
Step 4	To understand what is considered as a successful construction project, its key ingredients	• How is construction project success is measured? • Which factors affect the success of construction projects?	Literature Review/ Survey
Step 5	To investigate the main implementation barriers/obstacles in universal BIM/Data-driven tools adoption	• What obstacles have been reported in the use of BIM/Data-driven tools? • How to avoid such pitfalls?	Literature Review/ Survey

There are three types of research - exploratory research, descriptive and explanatory research. The kind of study that will be chosen for any analysis is dependent upon the way the research question is stated. This piece of work has adopted a descriptive approach and aims to set the scene of the subject in question and eventually draw conclusions from it. Such type of research does not seek to find the causality links, and the given situation under investigation is not modified but accepted as it is (Leedy & Ormrod, 2010).

In building the theoretical base of this research, secondary data were obtained from the related literature sources such as books, journal articles, conference proceedings, reports, papers in periodicals. The primary purpose of this stage was to establish a knowledge base on BIM and data-driven construction in the industry.

5.2 Techniques for Data Collection for this Thesis

The data for this Thesis was collected by using semi-structured interviews and web-based questionnaire. (As survey research strategy has been selected). Qualitative data obtained from the interview has been analysed based on the interpretative method. Data collected from the web-based questionnaire, which consisted of both open and closed questions, has been analysed using interpretative and statistical methods.

Questionnaire Design

An electronic questionnaire is proved to be the fastest way to contacting a large number of participants in a limited amount of time. In creating and running the online questionnaire for this research topic, it was decided to use an online survey application called SurveyMonkey. Such a tool is also an effective way to analyse the received answers to interpret the data.

The design of the questionnaire is based on the findings collected through literature review (Appendix B contains a copy of questionnaire). In this research, close-ended, as well as open-ended questions, were asked to obtain information from the research participants. Such variety in questions will allow for a variety of received data and its further analysis.

In avoiding any bias, the respondents were allowed to enter their response by selecting the ”other” field. Also, the web-based questionnaire did not provide the chance to have answered, ‘don’t know’ and ‘not applicable’ or ‘N/A.’

The questionnaire consists of factual as well as opinion-based questions. While real questions aimed to obtain information related to the background of an individual or a company, their projects or professional cases, the opinion-based question was used to get the respondent's view regarding the phenomena.

Due to the possibility of low response rates, it was decided to design the questionnaire with compulsory answers to most of the questions. It should help to avoid partially completed questionnaires where it's possible to skip some question or withdraw from the survey at any point.

In the timeframe of 2 months, only 20 fully complete questionnaires were obtained.

Interview Design

The purpose of conducting interviews for this research topic was to gain valuable insights and data based on the professional experience of the interviewees. It was decided to conduct semi-structured interviews due to their less strict format, absence of a formalized list of questions and ability to ask open-ended questions. The rule that the researcher has followed is to ask brief questions and allow the interviewee to speak, while the researcher listens attentively.

Interview questions were designed through some key findings from the literature review, as well as the further questions on discoveries made during the questionnaire period (Appendix A contains Interview questions). To find more professionals who had extensive experience with BIM and Data-driven construction tools, the researcher utilized an online platform of professional network – LinkedIn. In total, the researcher has contacted more than 40 professionals working in the construction industry, who also have extensive experience in using digital tools. Among those, only four have agreed to conduct the interview. They were able to talk to the researcher via Zoom due to the current pandemic situation with the COVID.

At the beginning of each interview, the respondent was informed about the research purpose. Also, permission to record the online interview was asked. The opening questions of the interview were general and were related to the respondent's education, experience, current employment. Then each participant was asked questions related to the measurement of success on construction projects. The problems were related to the ability of current data-driven technology to affect such success. The utilization of BIM and data-driven tools in their practice, benefits they see using it, drive for its usage, its limitations and challenges, as well as the ways they address and solve such issues in their workplace.

5.3 Response Rates

Questionnaire

The data from the questionnaire has been collected over two months which started on 13th August 2020 once the web-based questionnaire was live. The questionnaire link has been distributed within LinkedIn contacts, groups and communities, who were currently employed in the industry and had an experience in using data-driven tools and BIM. It has also been requested by the respondents to forward the questionnaire to any relevant colleague or friends. They had to satisfy the criteria of this research responder as well. To collect reliable information and ensure a reasonable response rate, the researcher also distributed the questionnaire to companies and associations in the construction industry.

There were instances when the respondents did not fully complete the questionnaire, notwithstanding the partial completion of some sections, such responses were counted as inappropriate and were eliminated from the final data set.

Interviews

To increase the number of potential interviewees among construction professionals, it was decided to start with the distribution of the web-based questionnaire and try to interest respondents with the possibility to interview them later in the process. The last question of the questionnaire was about the interest of a respondent to be interviewed. They were also asked about the possibility to give their contact details for that purpose was presented. Ten questionnaire respondents have provided their contact details to get in touch for an interview. However, eventually, only four people were interviewed (due to no response from the other six people). The interviews represented the 2nd stage of the research. They were intended to provide a deeper understanding of the subject of the study from the professional point of view.

5.4 Sampling and Respondents Information

Sample, in research terms, can be defined as a smaller group of people or objects that are taken from a larger population. It is a subset of the people, that is taken for its further measurement. Since it not practical or in some cases impossible to study the whole population, representative in the form of a sample can be used to generalize the findings (Burgess, 2001)**.** Such sampling technique is viewed as the most suitable means to address the research objectives and allows for a reasonable number of responses from the population, upon which researcher can obtain a piece of detailed information (Bryman, 2001) (Sarantakos, 1998)**.**

The questionnaire link of this Thesis has been distributed through various professional communities, websites and groups related to the construction industry. There were two main criteria for selecting sample respondents, which are employed in the construction industry and experience in using data-driven tools and BIM.

Preliminary questions were asked at the beginning of the interview, as well as web-based questionnaire, so that such information as the name, job position, location, main work activity of the company and years of experience in the construction industry was defined. Such data were collected to obtain background for data analysis.

It must be noted that the researcher initially did select Europe as a specific region for the research; however, did not put a restriction on the particular country of work for the respondents. It was done due to the difficulty of finding enough respondents from only one specific country to the questionnaire as well as interviewees who would be interested in spending their time for an interview. Eventually, the sample of people who responded included countries outside of Europe too. Therefore, it must be considered that different countries have their unique understanding, experience and mentality in the construction industry and levels of usage of data-driven tools and BIM. Tables 6 and 7 below provide a summary of the respondents who undertook the interview and the questionnaire.

Table 6: Information about interviewed respondents

No	Job Position	Main Services of the Company	Work Location	Years of experience in the industry
1	BIM Manager	Construction Management Consultancy, Structural Design, MEP Design	Singapore	7-10
2	Head of BIM	General Contractor Services	UK	15-20
3	Development Engineer	General Contractor Services, Construction Management Consultancy, Real Estate Development	Finland	7-10
4	Technical Lead	Lifecycle Data Management	Finland	10-15

Table 7: Information about questionnaire respondents

No	Job Position	Main Services of the Company	Work Location	Years of experience in the industry
1	BIM consultant	Support and Consultancy	Sweden	More than 20
2	BIM Specialist	General Contractor Services	Finland	4-7
3	Schedules and design manager	Construction Management Consultancy	Finland	10-15
4	Structural Engineer	Architecture/Design, MEP Design, Structural Design, Construction Management Consultancy	Finland	4-7
5	Chief Digital Construction Officer	General Contractor Services	Finland	More than 20
6	Development Manager	General Contractor Services, Construction Management Consultancy, Real Estate Development	Finland	More than 20
7	Development Engineer	General Contractor Services, Construction Management Consultancy, Real Estate Development	Finland	7-10
8	Head Project Information Management	General Contractor Services	Malaysia	More than 20
9	Construction Lead for BIM/Digital	Architecture/Design, MEP Design, General Contractor Services, Construction Management Consultancy, Real Estate Development, Client/Owner	UK	4-7
10	Head of BIM Marketing	MEP Design, Software Development	Germany	4-7
11	Project Manager	Advisory Services/ Consultancy, Program Management, BIM Consultancy/ Management, Specialists (Fire, Light, Facade, Acoustics, Physics), Change Management, Automation, Infrastructure, Aviation, Water	Germany	7-10
12	Head of BIM	General Contractor Services	UK	15-20
13	Planning Manager	General Contractor Services	India	More than 20
14	Team leader	Client/Owner	Finland	More than 20
15	System and process improvement manager	Architecture/Design, Structural Design, MEP Design, General Contractor Services, Construction Management Consultancy	India	10-15
16	Design Manager	Construction Management Consultancy	Finland	More than 20
17	Manager BIM Strategy	Structural Design, MEP Design, Architecture/Design, General Contractor Services	India	10-15

18	BIM Manager	Construction Management Consultancy, Structural Design, MEP Design	Singapore	7-10
19	Cost Manager	Construction Management Consultancy	Germany	1-3
20	Technical Lead	Lifecycle Data Management	Finland	10-15

5.5 Research Findings

5.5.1. Success Measurement of Construction Projects

Questionnaire Results

The majority (85%) of respondents confirmed that the companies they are employed to measure the success of their projects. Regarding the factors, half of the respondents agreed that timely completion, as well as on-budget completion of a project, are an essential success factor. Furthermore, 40% of respondents view quality as a success measure, thus confirming the general view of the importance of the iron triangle. At the same time, respondents gave high priority to customer satisfaction (39%) which they view as a guarantee of a future project with the same client or client recommendation for winning new customers. Profitability (28%) and safety (17%) of a project are also considered as an essential measure, as illustrated in Figure 17 below. However, these were secondary to most of the people.

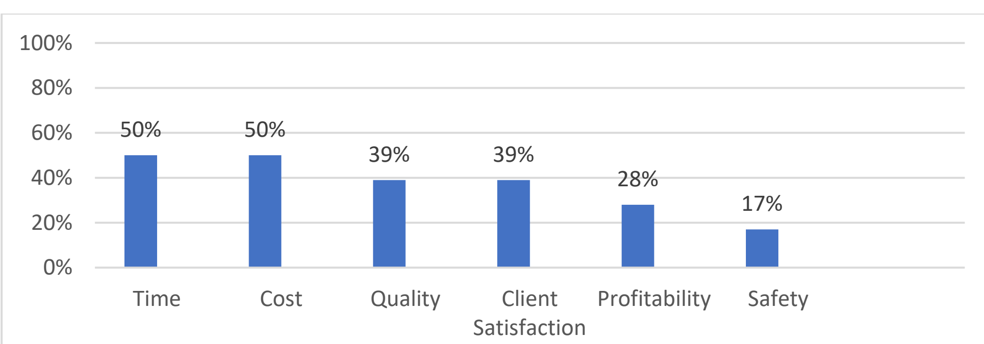

Figure 17: Terms of project success measurement

In the understanding which factors, affect the success of their projects, further questions were asked. 7 out of 20 respondents have mentioned communication, collaboration (information sharing) and teamwork as primary factors that can influence the successful completion of a project. Also, two people said that the allocation of the right people, as well as a qualified team, can play a significant role in a project. Only one respondent mentioned the well-being of personnel as an essential factor for project success.

Adequate planning ahead, getting involved early on and giving yourself enough time for preparation (3 out of 20 respondents) was also considered necessary for the project. Such allowance of time was believed to help to make realistic and also reliable estimation of time and budget required to complete the project (4 out of 20 respondents). Among other factors, risk management, disciplined site management, regular cost forecasting, contract management and subcontractor contract models were mentioned.

Only three people out of twenty mentioned technology as being an essential factor; this included appropriate software, Quality of digital models as well as precise data strategy.

Interview Results

Interview respondents also had similar views about the measurement of success; all have mentioned the timely completion of the project as well as the economic goals being met. One respondent has particularly noted the importance of monitoring of the program and productivity as well as the ability to intervene if necessary, to make some corrective measures. Another respondent mentioned safety as being the first factor for measuring project success and the absence of environmental damage to nature.

5.5.2 Ability of BIM/Data-Driven Construction Tools to Influence Success on Construction Projects

Questionnaire Results

90% of questionnaire respondents replied positively to the question of the ability of BIM to contribute to the success of projects. While 10 % said no in which 5% said not now, but in future.

Next, an open-ended question was asked to explain their positive or negative answer to the previous question. The reasons that were stated for answering “no” to the problem were explained as project success not being dependent on BIM/Data-driven tools themselves, but the process of synchronizing (integration) and working hand in hand with other trades.

While the other answer stated that data-driven tools could improve projects such as IoT and drones can improve the information collection and further decision making, Robotics can improve productivity. AI can help planning and controlling scheduling; etc. however, they cannot affect project success globally.

Those who answered positively to the previous question explained their answers in the following way:

BIM/Data-driven tools contribute to project success because:

- They provide accurate, clear data (organized into useful information) available to all involved in the project, at the right time, thus giving a chance to make better-informed decisions;
- Improve communication and collaboration, reduce the risk of problems on-site;
- Adopt more effective processes (but people still playing the main role);

- Minimize human factor, thus fewer mistakes, which leads to less time spent and cost;
- Enable risk identification and their early mitigation through a digital image of the project;
- Allows for better visual understanding;
- Allows better coordination of design material, quantity take-offs and site-level model-based communication through mobile solutions such as Trimble Connect;
- All cloud-based Project databases (Office 365) and therefore accessible from anywhere, lowers the risk of data losses and through unified form collection and comparison of project data is easier and faster;
- Drones are used for documenting significantly larger infrastructure projects, which can save time too but first of all, allows for more extensive documentation coverage, which can be useful later in information queries and disputes.

Interview Results

Two (2) opposite opinions about the ability of BIM and Data-driven tools to influence the success of undertaken projects were discovered during the interviews. On the positive side, some believe BIM can improve communication, in terms of faster loops of communication, therefore, more immediate responses to any problems or changes, early reactions and influences, an informed decision made on reliable information. Also, the visual capabilities of BIM are essential for successful communication with the client to make sure the client understands what is being talked about exactly. The ability of BIM to improve cost estimations has also been mentioned.

Some respondents believed that BIM promotes more collaborative behaviour between the project participants and can provide better outcomes of the project through again improved communication. However, such benefits do not just happen; according to the Interviewee, people still need to play their part through following the right process and procedures.

On the other hand, some do not believe that technology can contribute to the success of projects, by giving examples of successful projects that were built earlier without using such technological abilities. Respondent acknowledges that BIM is not a key player; it should play the supporter role. *“Perceptions and expectations of BIM from people are high, but they should realize that BIM requires everyone to participate in the process, to give their input and help. The success of BIM implementation is also attributed to how well BIM can integrate into each of the workstreams such as design management, schedule and cost management, etc.”* according to one of the Interviewees. Accordingly, the Interviewee mentioned that poor adoption and process integration of BIM is linked to a silo mentality that is typical for the construction industry.

5.5.3 Awareness and Utilization of Data-Driven Construction Tools

One of the crucial factors for this research was the level of awareness and utilization of data-driven tools as well as BIM. The findings demonstrate that half of the respondents come from organizations which are aware of Big Data and are utilizing it for their projects.

Figure 18 below shows the types of data-driven tools that are used in the organizations of respondents’ employment. Some respondents utilize not only one but several such devices. As can be seen, form the graph above, Cloud Computing (70%), Drones (70%) and Internet of Things (50%) are the most widely used tools at the moment. Cloud computing and Drones are used by most of the respondents irrespective of the primary services of their company.

Other tools which are used by the respondents, but not specified in the frame of this research are Software Robotics/Robotic Process Automation, Linked Data, BIM-based design tools and information management systems.

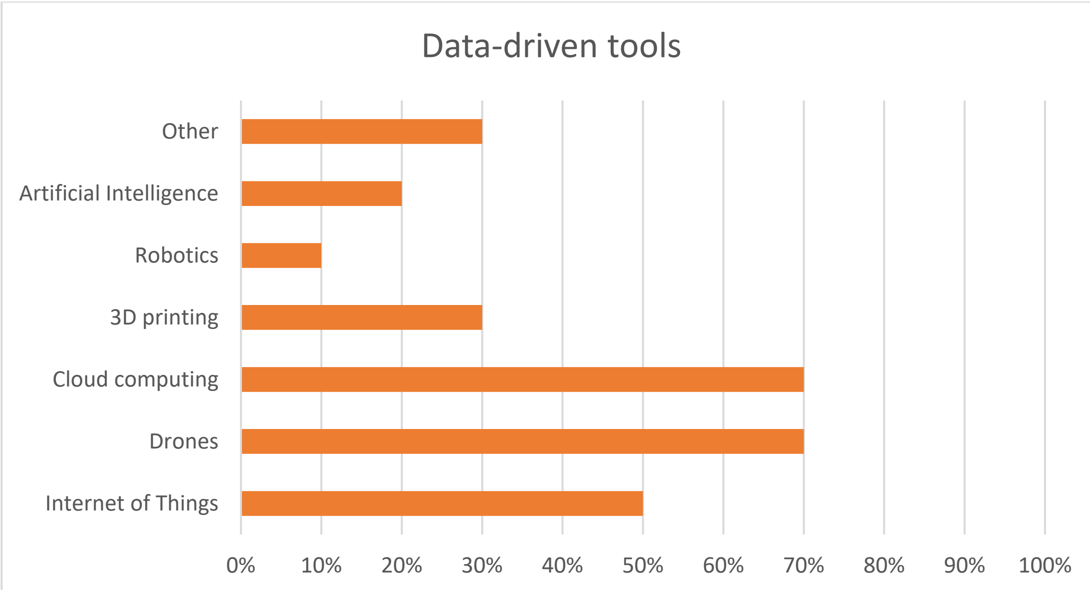

Figure 18: Types of Data-driven construction tools used

Figure 19 below demonstrates that the adoption of such technology is driven mostly by the management of the company. It is evident in 70% of the cases, and 55% of cases by a specific department of companies. Clients also play a crucial role in promoting such tools. They account for 40% of the cases. It is important to note that 10% (Other) of respondents say, that individual project managers or champions, selected people who internally drive specific vital topics are also driving such technology adoption.

5.5.4 Known Benefits of Data-Driven Tools

It is worth noting that only 5% believe that data-driven tools do not affect their project performance. Therefore 95% of respondents state that they are able to make a difference in construction projects. 85% of questionnaire respondents believe that such tools save time and improve quality on a project, while 80% state that is saving costs are also possible. Raising productivity (60%), increasing safety on sites (35%) and reduction of environmental effect (20%) are also known as proved benefits, according to Figure 20.

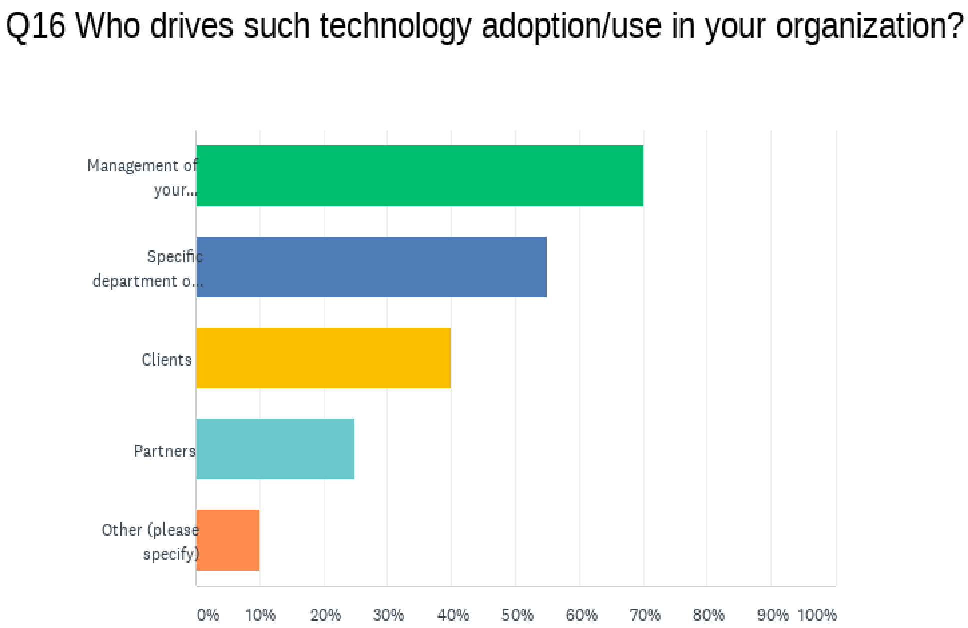

Figure 19: Drivers of the Data-driven tools

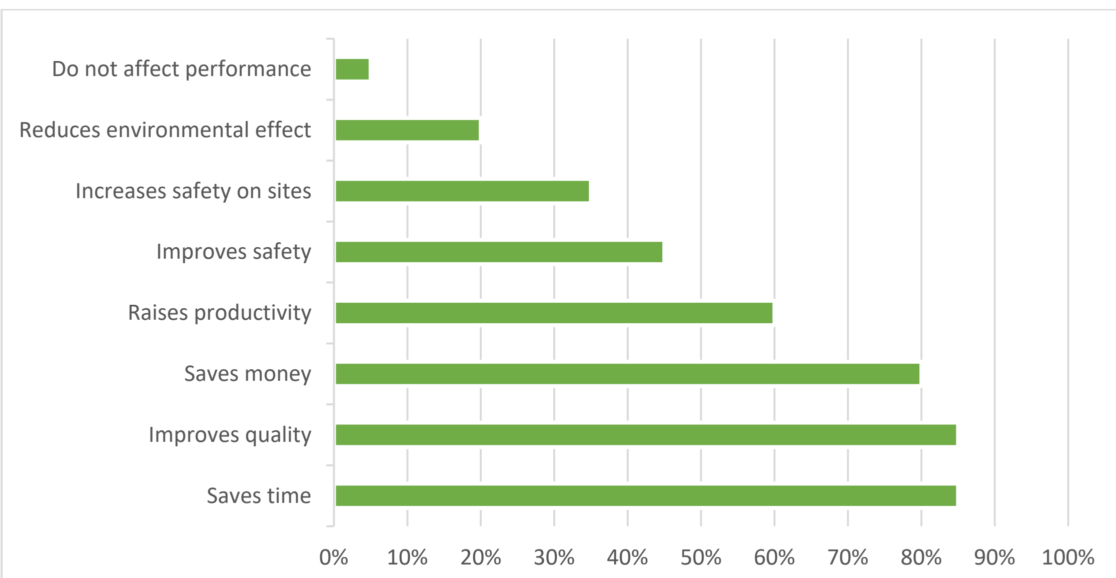

Figure 20: Proven benefits of Data-driven tools on construction projects

5.5.5 Difficulties and Challenges While Introducing and Using Data-Driven Tools

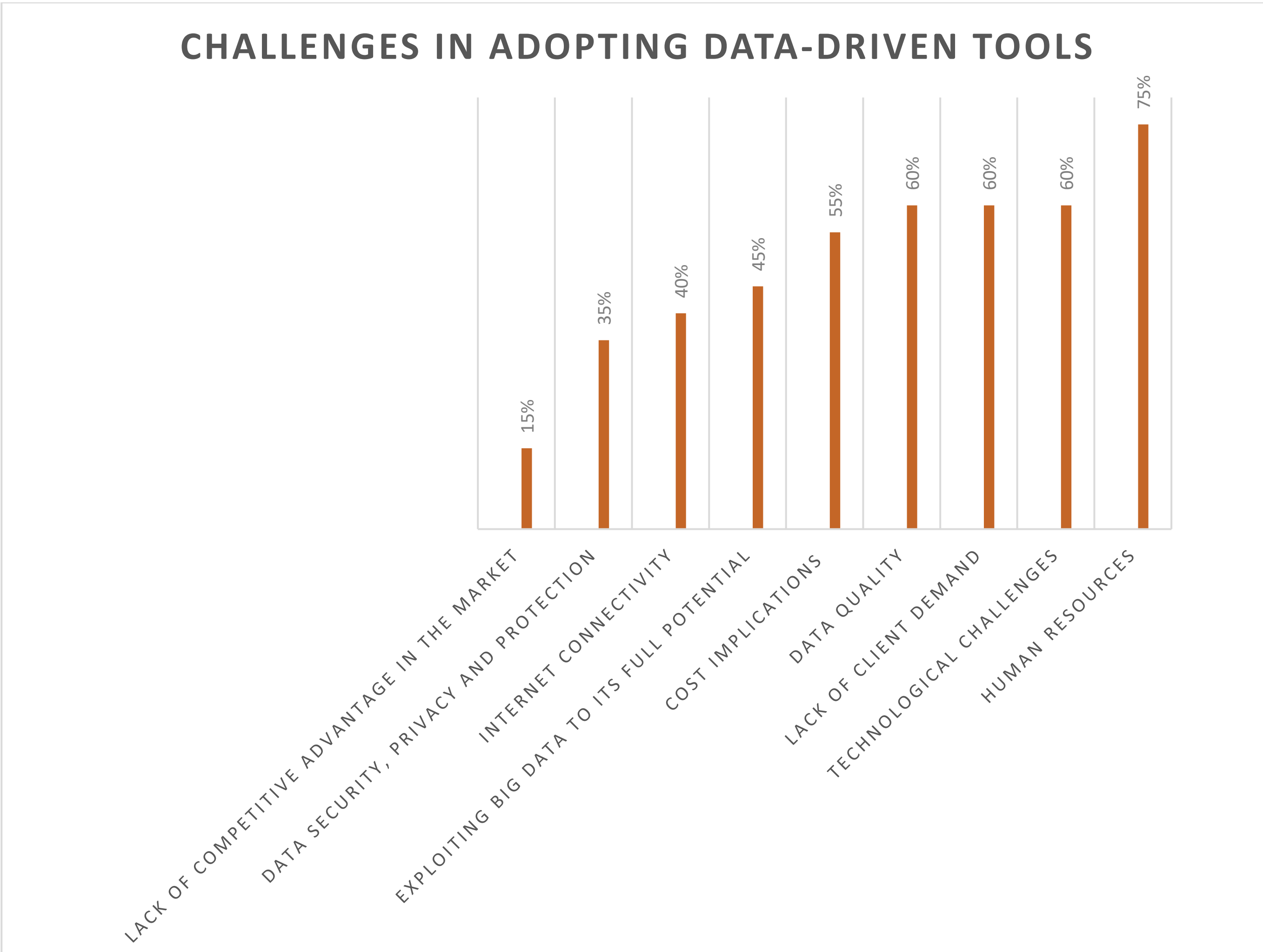

Figure 21: Challenges in adopting Data-driven tools

The biggest challenge that was experienced by the respondents during their adoption of data-driven tools was human resources factor (75%), as can be seen in Figure 21 above. However, it does not correlate with the findings from the literature review.

Technological challenges as well lack of clients' demand (both 60%) represent the second and third-biggest challenge according to the respondents, which is somewhat similar to the literature review.

Data quality (60%) and cost implications (55%) were also mentioned in the literature. High-value analytics cannot be derived from the low-quality data, and substantial financial investment is required to operate software, hire professionals, maintain data centres and all the networking infrastructure. Respondents believe that internet connectivity is also a challenge since remote sites and offices need to be connected through the internet to monitor the progress of work in real-time.

Data security is considered as a challenge by 35% of respondents, similar to literature reviews, protection of data and measures to control and protect the access to it is a concern that keeps the levels of Big Data adoption low.

5.5.6 BIM Use and Its Proven Benefits

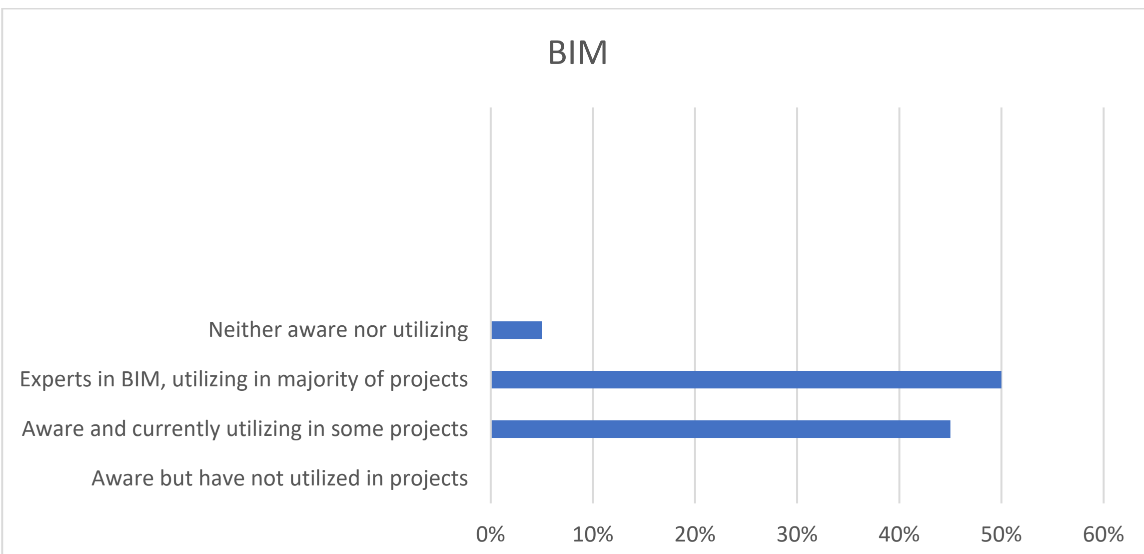

Figure 22: Awareness of BIM

95% of respondents stated that they are aware of the BIM existence, whereas 45% of them have used it in their projects (Figure 22). Another 50% of the respondents considered their companies as BIM experts and used BIM for the majority of their projects. According to the respondents, BIM is used in their companies for both public and private sector projects, commercial and industrial buildings. See Figure 23 below for a more detailed breakdown.

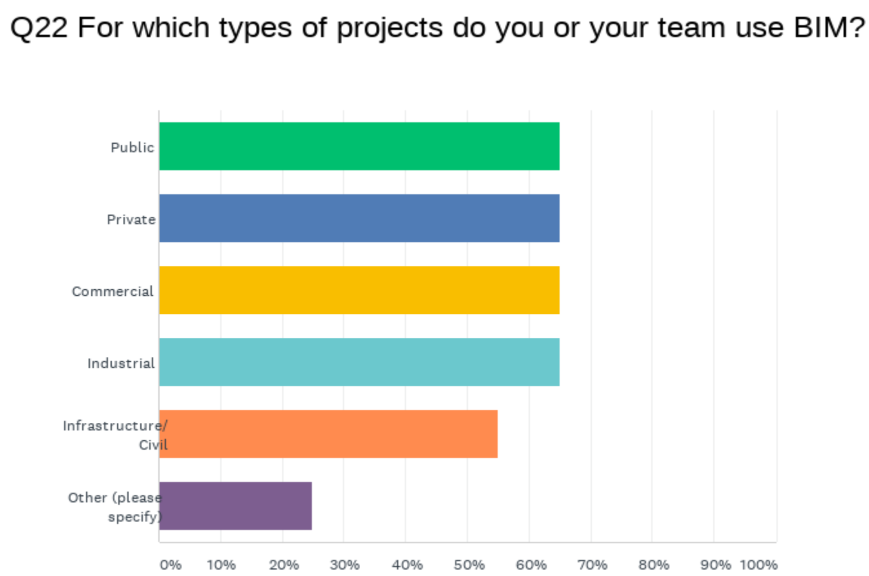

Figure 23: Types of Projects

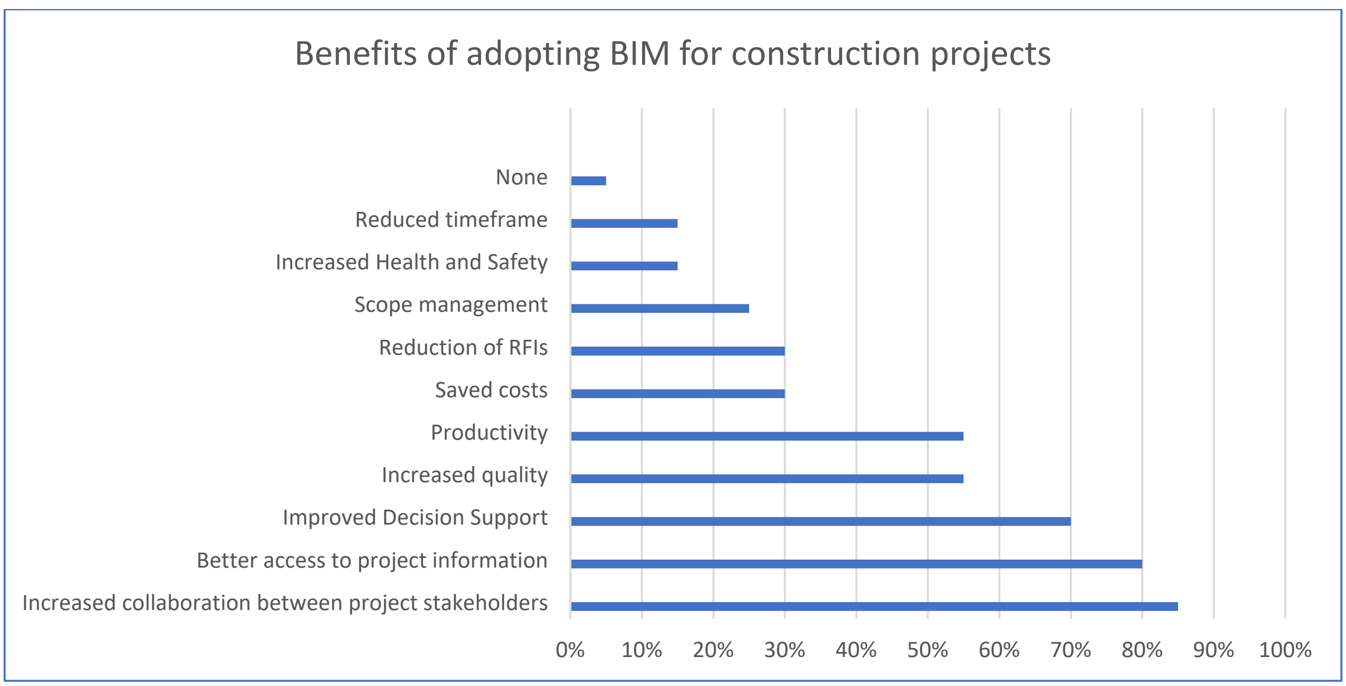

Figure 24: Proven benefits of adopting BIM on projects

85% of respondents claim that BIM adoption has helped to increase collaboration between the parties involved in their projects, while 80% say it allowed them to have better access to project information. This can be seen from Figure 24. Such results from the research is a confirmation of information found in the literature review. Next, 70% say they now have improved decision supports. Quality and Productivity increase is claimed by 55% of all respondents. Benefits such as saved time and money are only 15% and 30% respectively.

5.5.7 Obstacles and Difficulties of Adopting BIM

As demonstrated in Figure 25, there are all sorts of barriers which exist on the way to BIM adoption. The leading position of obstacles belongs to lack of BIM standardization (70%), 65% are claiming the process barriers such as facilities, and 60% of people and organizational culture. It is also consistent with the literature. All of these factors have been discussed in Chapter 3 of this research.

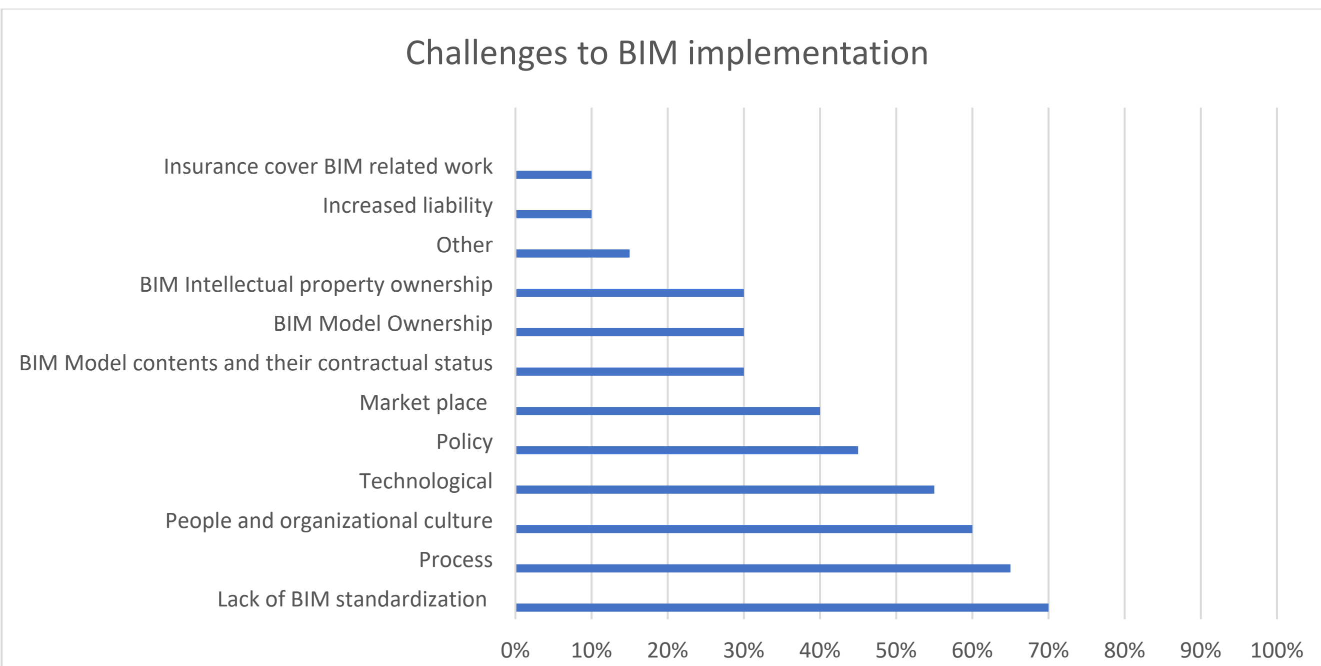

Figure 25: Challenges experienced with BIM adoption

5.5.8 Recommendations and Suggestions for BIM Implementation

Respondents were asked their experience in improving the adoption of BIM. Their recommendations will be summarized below.

Standards or guidelines as a common practice are mentioned a lot. The recommendation was for standardization to be taken care of in the first place. It is implemented and used by all participants. A burden for all stakeholders is emphasized when each is using and demanding to learn their individual, often relatively immature solutions.

Training, education and general awareness about the tools and their benefits is an important point, as generally there are not enough adequate case studies and examples within the industry that prove the benefits of such devices. Training and building competencies should be continuous and on all levels of an organization, including site personnel as well as the higher management, whose support in applying specific technology solutions is essential.

Attention and support of higher management are also emphasized. Clients' power to drive more adoption, as well as mandatory public regulation, is spoken about in detail.

However, it has also been mentioned that best results usually come from companies that have their inner reasons for such technology adoption. Such implementation should be necessary for the company itself and be part of their own long-term goals, not just because the outer environment imposes it.

Quality of generated data as well as knowledge obtained through data should be managed well, through the transfer onto the next projects. Data should not be encapsulated within the organizations.

6. Conclusions and Recommendations

Introduction

This chapter concludes and presents a summary of achieved aims and objectives of the research which were attained through the existing literature, primary data collection and through overall study findings. The first section of this chapter will provide an outcome of the research objectives by highlighting key results of the research and analysing each research objective separately. The following section defines the limitations of the current study and gives recommendations for further studies.

6.1 Outcomes of the Research Objectives

Why Construction Projects are Underperforming?

Construction projects are very complex endeavours. They are also unique; a temporary and large number of parties are often involved. Due to its highly fragmented nature, construction projects are prone to a lot of complexities and challenges, at the same time to lower efficiency. The underperformance of projects is believed by some to be the outcome of its unique characteristics. In contrast, others think that failure to embrace emerging technologies and reliance on old inefficient processes is the reason for its underperformance.

What are the Main Project Success Factors?

The present research provides additional evidence about the importance and actuality of “iron triangle” for measuring success on construction projects, namely timely and on-budget completion, as well as to the specified quality, as identified in the literature review. These factors were all equally of first importance for all respondents whatever were the primary services of their companies, i.e. Consultancy firms, as well as General Contractors, Designers consider those factors as a foundation of success. However, along with those factors come personal objectives of each project stakeholder, such as profitability and client satisfaction, safety, minimal environmental impact, etc.

How can We Improve Construction Project Management Efficiency in Terms of Time, Cost and Quality with BIM and Data-Driven Construction?

According to the findings of the research, BIM is not only a technology but also a management process, which can positively affect collaboration between the project stakeholders and thus make construction projects more manageable.

What is clear from the findings is that such technologies as BIM cannot directly reduce the construction time of the project or reduce its cost. However, it can elevate the quality of the structure in terms of the reduced number of RFIs. And defects thanks to the digital 3D data.

The effect on BIM on time and cost of a project is not easy to measure, since there are so many variables and factors which can affect construction project and most importantly every project is unique and different. However, it can be so that the project timeline and cost is reduced with BIM due to the new productivity and efficiency achieved with it.

Data-driven construction tools also do not directly affect how fast the construction is going to be and how much it is going to cost, this is possibly a matter of time since with the wide use of robots and AI such changes might be possible.

At present, some data-driven tools help to gain accurate and useful information about the project, thus allowing for better communication and decision making. Tools such as Cloud computing, for instance, keep all project information in a cloud-based form, thus lowering the risk of data loss, as well as access to it instantly from anywhere.

Drones, for instance, allow for better visual documenting, especially on larger infrastructure projects, thus allowing to save time on some tasks as well as record the project for potential information queries and disputes.

All such tools are essential, and they add value. However simply adopting them does not guarantee the improvements of construction project management process, it is also crucial that such technologies are deployed by the right people and in a proper way due to the possibility of further fragmentation and other complications.

What is the Value of BIM and Data-Driven Construction Already Known and Being Benefitted from Using?

According to the findings of the research, BIM and data-driven construction tools positively affect construction projects. In the case of BIM, to ripe the benefits, a clear strategy must be present and also BIM work procedures should be followed. According to the literature review and also confirmed by the respondents, the main benefit that BIM brings is increased collaboration between the various project stakeholders, which is very valuable in an industry that is highly fragmented. Most of BIM users highly benefit from the better access to project information that is available in 3D format. Such easy access to project digital model serves informed decision making.

The findings of this research demonstrate and confirm literature findings of the ability of BIM to influence Productivity and Quality of a project in the form of reduced RFIs and defects.

Data-driven tools are regarded as tools that can help saving time and money through raised productivity and safety on construction sites. Respondents also pointed out their abilities to improve quality with, for instance, robots, 3D printing, as well as reduce the environmental effect of the construction.

What More can be Achieved with Such Tools?

Labour-intensive activities on construction site lead to low productivity, low quality of work as well as potential injuries. Conventional work methods cannot solve such problems. However, robots may have the possibility to solve such issues when they are used to their full potential, which includes a reduced amount of workforce on site. A particular job can be guaranteed with the robotic control, sensing, mapping, localization and planning. It is expected that with the advancement of BIM and artificial intelligence technologies, adoption of robotics will be pushed further.

AI also offers a lot of potential benefits that can solve the construction industry's inherent problems with Health and Safety, Quality and Scheduling. Adoption of AI is low at the moment, however, in such technology is used in future, it can enhance construction projects through its properties of detailed analysis, prediction, detection and pattern recognition abilities.

What are the Pitfalls, Limitations and Implementation Barriers of BIM and Data-Driven Construction into the Industry?

Understanding of what limits the widespread adoption of technology is essential to develop relevant strategies to overcome such pitfalls. Hence, the main barriers found (technical as well as non-technical) were further investigated and compared to the existing literature.

The present study provides additional evidence concerning implementing BIM that it is not an easy task and should be considered not only at the organizational level but also on a national level.

One of the main challenges, according to the investigations carried out, is a lack of standardization. It was also already mentioned in the literature review. Absence of a single exhaustive regulatory document - a standard for everyone compulsory to use makes the process harder. Since everyone who is using BIM, uses their own self-centred, fragmented guidelines and rules, it is making difficult for the operation of cooperating with others inefficient and inflexible, thus hindering the expected results from BIM.

Process barriers to BIM contain the barriers related to infrastructure as well as product and services. The infrastructure of companies that are planning on BIM uptake, maintenance and set up of such facilities is a challenge to most firms. BIM has a lot of features and the extent to which such features will be integrated into the model and the cost of such services is an important point that can slow down the process of implementation.

Pitfalls associate with people, as well as organizational culture is also one of the difficult ones. Successful adoption of BIM requires the right people with competencies needed on board. Resistance to change and behavioural changes are not easy to tackle. BIM requires a shift in construction process culture, which is about collaboration with others. Switching to BIM-enabled work environment requires strong motivation and leadership in a company. Sufficient and up-to-date training and up-skilling of employees is to be taken care of; this is necessary to avoid varying levels of user experience on projects.

Recommendations and Suggestions for Improving /Increasing the Data-Driven Construction and BIM Implementation

In overcoming the barriers that were identified during this research, several structural changes are needed. First of all, developing a common national or international BIM guidelines and standards, so that everyone in the industry is applying the same rules and standards in their BIM modelling and processes.

Since the process is driven by people and not technology, investing in education, training, capacity building is essential. Research and positive case studies will make people more aware and will reinforce the motivation to implement BIM in their companies.

Training, education and general awareness about the tools and their benefits is an important point, as generally there are not enough adequate case studies and examples within the industry that prove the benefits of such devices. Training and building competencies should be continuous and on all levels of an organization, including site personnel as well as the higher management, whose support in applying specific technology solutions is essential.

Attention and support of higher management are also emphasized. Clients' power to drive more adoption, as well as mandatory public regulation, is spoken about often.

However, it has also been mentioned that best results usually come from companies that have their inner reasons for such technology adoption. Such implementation should be necessary for the company itself and be part of their own long-term goals, not just because the outer environment imposes it.

Quality of generated data, as well as knowledge obtained through data, should be managed well, through the transfer onto the next projects, data should not be encapsulated within the organizations.

6.2 Limitations of the Research

The time frame has restricted the depth of this research. The size sample of respondents also denied it. Such reasons have set limits to more empirical data collection for the analysis. It would have been better to collect more data through a larger sample of respondents as well as to conduct more interviews with the professionals in this industry.

Understandably, a larger size of a sample could provide more reliable results of the research, however, given the current study circumstances, the author was unable to find more people who were willing to participate in this research.

It was due to the unavailability of a larger sample of respondents from each of the several countries. It has been decided to collect the data from all available people working in the construction industry without any regional limits. Such decision has an impact on the validity of the study because each country and region have its level of BIM and data-driven construction awareness, use, adoption rates, as well as own reasons and challenges for widespread use of such technologies. Therefore, it must be noted that people surveyed for this study come from different countries and have different views and experiences with construction technology adoption, what is valid for one country, may not be useful for the other.

The author has noticed that the differing levels of BIM and data-driven technology adoption in terms of government support or company initiatives have a significant impact on the general feeling of people about the technology. Each country has its challenges that might be unique to them only, different levels of thinking and problem-solving results in different outcomes. Therefore, one must bear in mind that this research might not be the ideal representation of the universal pitfalls of BIM and data-driven tools adoption because it is based on several different countries.

The author thinks that reaching a universal solution to the problem that is the subject of this research is not possible due to varying levels of BIM and data-driven construction understanding, motivation and priority in different countries. It is necessary to study the country-specific level of BIM awareness, use as well as challenges to its comprehensive implementation and then the solution to the problem must be developed.

6.3 Further Study Recommendations

In this Thesis, the author tried to answer the questions related to the pitfalls of BIM and Data-driven construction tools. To further enable BIM implementation in the industry, more comprehensive further research is needed.

First of all, there is a need for more positive case studies, stories of BIM-enabled projects that were successful and their positive effect on work processes on construction projects. Lack of such information is evident, and unfortunately, this does not help in educating and promoting it to the construction community and industry clients.

Secondly, to create such case studies and show their effect on projects, explicit and systematic way of measuring BIM benefits is to be developed that can be used universally by everyone. Measuring BIM benefits is not an easy task, since every project is unique and possesses a lot of different variables.

Summary

The primary purpose of this Master Thesis is to examine the contribution of BIM and data-driven construction to the success of construction projects and to analyse the existing pitfalls and barriers to widespread adoption of such technologies. The construction industry has a profound impact on the world's economy; therefore, the success of construction projects is vital for everyone. The current image that the industry has is unattractive and is related to constant inefficiencies, overspend, delays, waste, etc. However, it is said that the latest technology innovations can present the industry with the opportunity to improve.

Claims have been made about the ability of data-driven construction tools to improve collaboration among the numerous parties to construction project, through the increased ease of information navigation and improved working processes. Better informed decisions and real-time monitoring promise to better management of time and cost, as well as improved quality of work. Notwithstanding the potential abilities of such technology, there are still challenges to its widespread adoption. This research will search for reasons behind such phenomena.

This Master Thesis is composed of six (6) chapters, each of them dealing with a different aspect of the research. Chapter 2 views the main characteristics of the industry and their effect on the performance of construction projects. Temporary nature of projects, technical complexities, a high number of different project parties, increased fragmentation, etc. all leads to inefficiencies and sophistication during the construction. In other words, industry attributes are the reason for their chronic underperformance. Next, the definition of success factors is searched for in construction projects. The results show that factors such as timely on-budget completion of a job and to required quality are the primary measures of success on construction projects. Additionally, some parties view health and safety, environmental and technological aspects, the satisfaction of clients and employees to be an essential part of success.

Chapter 3 views BIM as a valuable technological tool for the industry due to its dynamic and multi-dimensional information content, as well as multidisciplinary work environment which gives the opportunity to facilitate more collaboration among the project parties and can be used for the duration of the whole life cycle of a building. Later, BIM is also viewed as a project management tools, which has the potential to affect schedule, scope, cost and quality of construction projects. Challenges associated with widespread implementation of BIM in the industry are discussed, and they are found to be related to technological barriers, lack of standardization policies, legal framework and human resistance of change.

Chapter 4 concentrates on Big Data and Data-driven construction tools such as cloud computing, Internet of Things, drones, 3D printing, robotics and Artificial Intelligence. Their abilities to improve the construction management process, allowing the opportunity to capture relevant data, store and analyse it to make a better decision during the construction process.

Abilities of such tools to elevate the quality of work, as well as an increase of safety for construction workers, are believed to be vital for ensuring success. However, again, financial, legal, security, cultural barriers exist.

Chapter 5 defines the research strategy that was adopted for this thesis, as well as explaining the data collection techniques and general methodology used. Descriptive, mixed-method research has been adopted for this work. Through the review of available data collection techniques and consideration of their benefits and suitability for the present study, it was decided to adopt both qualitative and quantitative methods and conduct interviews as well as distributing a web-based questionnaire to gather primary data. Next, all the research findings concerning asked study questions were demonstrated and analysed, as well as comparison of the results to the existing literature was made.

Chapter 6 presents the main results and conclusions reached in the duration of research as well as providing recommendations for further study and talks about the main limitations of the study. Results obtained from the survey suggest that the success of construction projects is assessed through the iron triangle comprising of time, cost and quality, secondary factors are dependent on the position and work activities of a company in question. It has also been discovered that although the surveyed companies are very familiar with BIM and data-driven technologies and benefits, they could potentially bring. However, they still face challenges and pitfalls on the way to embrace the broader adoption of such technologies. Results show that lack of standardization, limitations related to process as well as barriers related to organizational culture. People are the main challenges on the way to complete adoption of technologies as mentioned above. In overcoming such pitfalls, there are several actions to be taken. It is advised to develop common international BIM guidelines and standards, as well as train industry people to a specific level so that working together with mutual understanding, is possible. And finally, it is essential to educate industry clients so that they drive the adoption of such technologies further.

Declaration of Authorship

I hereby declare that the attached master's thesis was completed independently and without the prohibited assistance of third parties, and that no sources or assistance were used other than those listed. All passages whose content or wording originates from another publication have been marked as such. Neither this thesis nor any variant of it has previously been submitted to an examining authority or published.

Berlin, 23.12.2020

Location, Date

Signature of the student

Appendix A

Interview Questions

1	What, in your opinion, is a successful construction project?
2	Can technologies such as BIM or Data-driven tools influence the success of projects? If yes, How? If not, why not?
3	What are the benefits of BIM?
4	Can BIM save time and money? How this can be measured?
5	Can BIM improve quality?
6	Who drives the adoption of BIM and data-driven tools?
7	Difficulties/challenges you face/have faced while introducing and using such tools?
8	How do you currently deal/overcome the obstacles as a company?
9	Could you please share your lessons learned from successful implementation of Data-driven construction tools and/or BIM in your organization?
10	Your recommendations and suggestions for increasing the implementation of data-driven construction tools and BIM in construction companies?

Appendix B

Web-based Questionnaire

Project success factors and pitfalls by using BIM and data-driven construction

Section A - Respondent's Details

1. Respondent's Name (Optional)

* 2. Respondent's job title / position (within the Company)

* 3. Respondent's Highest Qualification Level

* 4. Respondent's Years of Experience in Construction industry

- ◯ 1-3
- ◯ 4-7
- ◯ 7-10
- ◯ 10-15
- ◯ 15-20
- ◯ more than 20 years

Section B - Details of Company you are employed by

* 5. Which services does your Company offer?

- [ ] Architecture/Design
- [ ] MEP Design (Mechanical, Electrical and Plumbing)
- [ ] Structural Design
- [ ] General Contractor Services
- [ ] Construction Management Consultancy
- [ ] Real Estate Development
- [ ] Client/Owner
- [ ] Other (please specify)

* 6. Number of employees in your Company?

- ○ 1-10
- ○ 10-49
- ○ 50-249
- ○ 250 or more

* 7. Types of projects your Organization is engaged in?

- [ ] Public buildings
- [ ] Commercial buildings
- [ ] Industrial buildings
- [ ] Infrastructure / civil projects
- [ ] Other (please specify)

* 8. Geographical location of your workplace

Section C – Measurement of success

* 9. Does your Organization measure success on projects they are involved in? For example, in terms of time, cost, quality, etc.

- ◯ Yes
- ◯ No
- ◯ Other (please specify)

10. If yes, in which terms the success is measured?

* 11. Which factors, in your opinion and experience, affect the success of your projects the most?

* 12. Do you think that technologies such as BIM/Data-driven construction tools (such as Internet of Things, Drones, Cloud computing, 3D printing, Robotics, Artificial Intelligence) are able to influence your company's success on undertaken projects?

* 13. If yes, How and Why? If not, please also explain why not?

Section D - use of Data-driven construction tools in your Organization

14. What is the level of awareness of Big Data in your organization?

- ◯ Aware, but have not utilized in projects
- ◯ Aware and currently utilizing in some projects
- ◯ Utilizing Big Data in majority of projects
- ◯ Neither aware nor utilizing
- ◯ Other (please specify)

* 15. Which of the following tools of data driven construction do you use on your projects?

- ☐ Internet of Things
- ☐ Drones
- ☐ Cloud computing
- ☐ 3D printing
- ☐ Robotics
- ☐ Artificial Intelligence
- ☐ Other (please specify)

* 16. Who drives such technology adoption/use in your organization?

- ☐ Management of your organization
- ☐ Specific department of your organization
- ☐ Clients
- ☐ Partners
- ☐ Other (please specify)

* 17. For which project purposes were such tools selected to be used in your organization in the first place?

- ☐ To save time
- ☐ To save money
- ☐ To improve quality
- ☐ To improve safety
- ☐ To raise productivity/resource management
- ☐ To reduce environmental effect (reduce emissions, diminish waste, etc)
- ☐ To increase safety on sites
- ☐ It was Client's requirement to use such tool/s
- ☐ Other (please specify)

* 18. How do such tools actually affect your project performance? Its known/proved benefits.

- [ ] Saves time
- [ ] Saves money
- [ ] Improves quality
- [ ] Improves safety
- [ ] Raises productivity
- [ ] Reduces environmental effect (reduce emissions, diminish waste etc)
- [ ] Increases safety on sites
- [ ] They do not affect the performance/ They have no known/proved benefit
- [ ] Other (please specify)

* 19. Difficulties/challenges you face/have faced while introducing and using such tools?

- [ ] Technological challenges (interoperability, compatibility of software formats/versions, networking infrastructure)
- [ ] Data Security, Privacy and Protection
- [ ] Data Quality
- [ ] Cost Implications
- [ ] Internet Connectivity
- [ ] Exploiting Big Data to its Full Potential
- [ ] Lack of client demand (Client's attitude/appreciation of such tools)
- [ ] Lack of competitive advantage in the market
- [ ] Human Resources (Lack of trained people)
- [ ] Other (please specify)

Section E - use of BIM in your organization

* 20. What is the level of awareness/ utilization of BIM in your Organization?

- ◯ Just aware, have not utilized in projects
- ◯ Aware and currently utilizing in some projects
- ◯ Experts in BIM, utilizing BIM in majority of projects
- ◯ Neither aware nor utilizing
- ◯ Other (please specify)

* 21. Please specify on how many projects (%) do you or your project team uses BIM?

* 22. For which types of projects do you or your team use BIM?

- ☐ Public
- ☐ Private
- ☐ Commercial
- ☐ Industrial
- ☐ Infrastructure/Civil
- ☐ Other (please specify)

Section F – benefits of BIM for your Organization

* 23. What is the value of BIM that your Organization is already benefiting from on projects?

- [ ] Increased collaboration between project stakeholders
- [ ] Better access to project information
- [ ] Reduced timeframe
- [ ] Saved costs
- [ ] Increased quality
- [ ] Scope management
- [ ] Increased Health and Safety
- [ ] Reduction of RFIs
- [ ] Improved Decision Support
- [ ] Productivity
- [ ] Other (please specify)

Section G – pitfalls/obstacles of BIM adoption

* 24. What obstacles or difficulties have your Organization faced while starting to adopt BIM or during its use?

- ☐ Technological (Software, Hardware, Network)
- ☐ Process (Product and Service Infrastructure)
- ☐ Policy (Preparatory Contractual, Regulatory)
- ☐ Lack of BIM standardization (BIM guidelines, protocols)
- ☐ People and organizational culture
- ☐ Market place (Clients, Market Demand)
- ☐ BIM Model contents and their contractual status
- ☐ BIM Model Ownership
- ☐ BIM Intellectual property ownership
- ☐ Increased liability
- ☐ Insurance cover BIM related work
- ☐ Other (please specify)

Section H – Your recommendations/suggestions

* 25. Could you please share your lessons learned from successful implementation of Data-driven construction tools and/or BIM in your organization?

* 26. Your overall opinion about the ability of data-driven construction tools and/or BIM to affect construction project's success?

* 27. Could you please share/suggest ways to avoid the Potential Pitfalls along the way?

* 28. Your recommendations and suggestions for increasing the implementation of data-driven construction tools and BIM in construction companies?

29. In case you are interested to be interviewed on this topic further, please leave your contact details here.

References

European Commission, 2019. *European Construction Sector Observatory. Building Information Modelling in the EU construction sector,* s.l.: European Commission.

Abdirad, H., 2015. *Advancing in Building Information Modeling (BIM) Contracting: Trends in the AEC/FM Industry.* Milwaukee, USA, AEI 2015.

Ahadzie, D. K., Proverbs, D. G. & Olomolaiye, P. O., 2008. Critical success criteria for mass house building projects in developing countries. *International Journal of Project Management,* 26(6), pp. 675-687.

Al-Tmeemy, S. H., Abdul-Rahman, H. & Harun, Z., 2011. Future criteria for success of building projects in Malaysia. *International Journal of Project Management,* 29(3), pp. 337-348.

Anon., 2016. *Construction Extension to the PMBOK Guide.* 3rd ed. Pennsylvania: Project Management Institute.

Anon., n.d. s.l.:s.n.

Anyoha, R., 2017. *Harvard University Graduate School of Arts and Sciences.* [Online] Available at: The History of Artificial Intelligence [Accessed 28 March 2019].

Arayici, Y., 2015. *Building Information Modeling.* 1st ed. London: Bookboon.

Arayici, Y., Khosrowshahi, F., Ponting, A. M. & Mihindu, S., 2009. *Towards implementation of building information modelling in the construction industry.* Istanbul, Turkey, 5th International Conference on Construction in the 21st Century.

Armstrong, Geno; Gilge, Clay;, 2017. *Make it, or break it. Reimagining governance, people and technology in the construction industry. Global Construction Survey 2017,* San Francisco: KPMG.

Armstrong, Geno; Gilge, Glay; Max, Kevin;, 2019. *Future-Ready Index. Leaders and Followers in the Engineering and Construction Industry. Global Construction Survey 2019,* San Francisco: KPMG.

Armstrong, G. et al., 2015. *2015 Global Construction Survey: Climbing the Curve,* Denver: KPMG.

Arslan, V., Ulubeyli, S. & Kazaz, A., 2019. *UNMANNED AERIAL VEHICLES IN THE CONSTRUCTION INDUSTRY.* Gaziantep, UEMK 2019 Proceedings Book.

Atkinson, R., 1999. Atkinson, R. (1999). “Project management: Cost, time and quality, two best guesses and a phenomenon. It's time to accept other success criteria.. *International Journal of Project Management,* 17(6), pp. 337-342.

Azhar, S., 2011. Building Information Modeling (BIM): Trends, Benefits, Risks, and Challenges for the AEC Industry. *Leadership and Management in Engineering,* 11(3), pp. 241-252.

Barker, P., 2013. *BIM needs leadership,* London: Building.co.uk.

Bazeley, P., 2004. *Issues in mixing qualitative and quantitative approaches to research. Applying qualitative methods to marketing management research..* Basingstoke: Palgrave Macmillan.

Becerik-Gerber, B. & Rice, S., 2010. The Perceived Value Of Building Information Modeling in the U.S. Building Industry. *Journal of Information Technology in Construction,* Volume 15, pp. 185-201.

Berger, R., 2017. *Turning point for the construction industry. The disruptive impact of Building Information Modeling (BIM),* Munich: Roland Berger Focus.

Bilal, M. et al., 2016. Big Data in the construction industry: A review of present status. opportunities, and future trends. *Advanced Engineering Informatics,* 30(3), pp. 500-521.

Bock, T., 2014. The future of construction automation: Technological disruption and the upcoming ubiquity of robotics. *Automation in Construction,* Volume 59, pp. 113-121.

Bogue, R., 2018. What are the prospects for robots in the construction industry?. *Industrial Robot,* 45(1), pp. 1-6.

Borrego, M., Douglas, E. P. & Amelink, C. T., 2009. Quantitative, qualitative and mixed research methods in engineering education. *Journal of Engineering Education,* 98(1), pp. 53-66.

Borrmann, A., König, M., Koch, C. & Beetz, J., 2018. *Building Information Modeling. Technology Foundations and Industry Practice`.* Cham, Switzerland: Springer.

Brannen, J., 2005. *Mixed Methods Research: A discussion paper, NCRM Methods Review Papers,* Southampton, UK: ESRC National Centre for Research Methods.

Bryde , D., Broquetas, M. & Marc, J., 2013. The project benefits of Building Information Modelling (BIM). *International Journal of Project Management,* 31(7), pp. 971-980.

Bryman, A., 2001. *Social Research Methods.* New York: Oxford University Press.

Bryman, A., 2008. *Social Research Methods.* 3rd ed. Oxford: Oxford University Press.

Bryman, A., 2011. "Mission accomplished? Research methods in the first five years of leadership". *Leadership,* 7(1), pp. 73-83.

Buchli, J. et al., 2018. Digital in situ fabrication - challenges and opportunities for robotic in situ fabrication in architecture, construction, and beyond. *Cement and Concrete Research,* 112(October 2018), pp. 66-75.

Buehler, M., Buffet, P. P. & Castagnino, S., 2018. *The Fourth Industrial Revolution is about to hit the construction industry. Here's how it can thrive.* [Online] Available at: https://www.weforum.org/agenda/2018/06/construction-industry-future-scenarios-labour-technology/
[Accessed 6 June 2020].

Burgess, F. T., 2001. *A General Introduction to the Design of Questionnaires for Survey Research: Guide to the design of questionnaires.* 1st ed. Leeds, UK: University of Leeds.

Castro, F. G., Kellison, J. G., Boyd, S. J. & Kopak, A., 2010. A methodology for conducting integrative mixed methods research and data analyses. *Journal of Mixed Methods Research,* 4(4), pp. 342-360.

Chan, A. P., 1997. Measuring success for a construction project. *The Australian Institute of Quantity Surveyors,* 1(2), pp. 55-59.

Chan, A. P. & Chan, A. P., 2001. Key performance indicators for measuring construction success. *Benchmarking: An International Journal,* 11(2), pp. 203-221.

Chan, A. P. & Chan, A. P., 2004. Key performance indicators for measuring construction success. *Benchmarking: An International Journal,* 11(2), pp. 203-221.

Chan, A. P. C., Scott, D. & Chan, A. P. L., 2004. Factors affecting the success of a construction project. *Journal of construction engineering and management,* 130(1), pp. 153-155.

Chan, A. P., Scott, D. & Lam, E. W., 2002. Framework of success criteria for design/build projects. *Journal of Management in Engineering,* 18(3), pp. 120-128.

Cherkaoui, H., 2016. *BIM: Challenges and potential.* [Online] Available at: https://www.letsbuild.com/blog/bim-challenges-potential
[Accessed 8 October 2020].

Chovichien, V. & Nguyen, T. A., 2013. *List of indicators and criteria for evaluating construction project success and their weight assignment.* s.l., 4th International Conference on Engineering Project and Production.

Clavero, J., 2018. *Artificial Intelligence in Construction: The Future of Construction.* [Online] Available at: https://esub.com/artificial-intelligence-construction-future-construction/ [Accessed 28 March 2019].

Collis, J. & Hussey, R., 2009. *Business research: a practical guide for undergraduate and postgraduate students.* 3rd ed. Basingstoke: Palgrave Macmillan.

CONEXPO-CON/AGG, 2020. *Challenges and Opportunities for AI in Construction.* [Online] Available at: https://www.conexpoconagg.com/news/challenges-and-opportunities-for-ai-in-constructio
[Accessed 3 October 2020].

Creswell, J. W., 2003. *Research Design: Qualitative, quantitative and mixed methods approach.* 2nd ed. Thousand Oaks: Sage.

Davila Delgado, J. M. et al., 2019. Robotics and automated systems in construction: Understanding industry specific challenges for adoption. *Journal of Building Engineering,* 26(100868).

Denzin, N. K. & Lincoln, Y. S., 2008. *The Landscape of Qualitative Research.* 3rd ed. London: Sage.

Dryfhout, M. & Hewer, S., 2019. *What Is Cloud Computing?.* [Online] Available at: https://scouttg.com/blog/articles/what-is-cloud-computing/#:~:text=Cloud%20computing%20is%20the%20practice,server%20or%20a%20personal%20computer.
[Accessed 4 October 2020].

El-Sayegh, S., Romdhane , L. & Manjikian , S., 2020. A critical review of 3D printing in construction: benefits, challenges, and risks. *Archives of Civil and Mechanical Engineering,* 20(34).

Expert System, 2019. *What is Machine Learning? A definition.* [Online] Available at: https://www.expertsystem.com/machine-learning-definition/ [Accessed 28 March 2019].

Famous, G., 2018. *Three technology trends shaping the future of design and construction in 2018,* s.l.: Oracle Construction and Engineering blog.

Fellows, R. & Liu, A., 2003. *Research Methods for Construction Students.* 2nd ed. Oxford: Blackwell.

Franz, B. & Messner, J., 2017. *Evaluating the Impact of BIM on Project Performance.* s.l., Computer Integrated Construction (CIC) Research Program - White Paper 1.

Ghaffarianhoseini, A., 2016. Information Modelling (BIM) uptake: Clear benefits, understanding its implementation, risks and challenges. *Renewable and Sustainable Energy Reviews,* Issue 75.

Gilge, Clay; Armstrong, Geno;, 2015. *Digging into Data. A Blueprint for Mega-Project Success,* Denver: KPMG.

Gray, D. E., 2006. *Doing Research in the Real World.* London: Sage.

Gu, N. & London, K., 2010. Understanding and facilitating BIM adoption in the AEC industry. *Automation in Construction,* 19(2010), pp. 988-999.

Gu, N. et al., 2008. *BIM: expectations and a reality check.* Beijing, China, 12th International Conference on Computing in Civil and Building Engineering.

Harland, C., Lamming, R. & Cousins , P., 1999. Developing the concept of supply strategy. *International Journal of Operations and Production Management,* 19(7), pp. 650-673.

Heravi, G. & Ilbeigi, M., 2012. Development of a comprehensive model for construction project success evaluation by contractors. *Engineering Construction & Architectural Management,* 19(5), pp. 526-542.

Herrmann, M. J., 2018. Regulation of unmanned aerial vehicles and a survey on their use in the construction industry.. *Construction Information Technology - Selected Papers from the Construction Research Congress 2018,* pp. 758-764.

High, P., 2017. *Forbes. Carnegie Mellon Dean Of Computer Science On The Future Of AI.* [Online] Available at: https://www.forbes.com/sites/peterhigh/2017/10/30/carnegie-mellon-dean-of-computer-science-on-the-future-of-ai/#544374be2197
[Accessed 28 March 2019].

Hill, B. L., 2017. *Digging for the Big Data Gold in Today's Construction Projects,* San Diego: Xpera Group.

Holt, E. A., Benham, J. M. & Bigelow, B. F., 2015. *Emerging technology in the construction industry: Perceptions from construction industry professionals.* Washington, USA, ASEE Annual Conference and Exposition, Conference Proceedings, 122nd ASEE.

Hooper, M., 2015. BIM standardisation efforts - the case of Sweden. *Journal of Information Technology in Construction,* Volume 20, p. 332346.

Hughes, S. W., Tippett, D. D. & Thomas, W. K., 2004. Measuring Project Success in the Construction Industry. *Engineering Management Journal,* 16(3), pp. 31-37.

Information Technology Association Of America, 2019. *Information Technology Association Of America.* [Online]
Available at: http://www.connectlive.com

Irizarry, J. & Costa, D., 2016. Exploratory Study of Potential Applications of Unmanned Aerial Systems for Construction Management Tasks. *Journal of Management in Engineering,* 32(3), pp. 1-10.

Ismail, S. A., Bandi, S. & Maaz, Z. N., 2018. An Appraisal into the Potential Application of Big Data in the Construction Industry. *International Journal of Built Environment and Sustainability,* 5(2), pp. 145-154.

Jacobsson, M. & Linderoth, H., 2009. The influence of contextual elements, actors' frames of reference, and technology on the adoption and use of ICT in construction projects: a Swedish case study. *Construction Management and Economics,* 28(1), pp. 13-23.

Jayaraj, A. & Divakar, H. N., 2018. *Robotics in Construction Industry.* s.l., IOP Conference Series: Materials Science and Engineering.

Jogulu, U. D. & Pansiri, J., 2011. Mixed methods: A research design for management doctoral dissertations. *Management Research Review,* 34(6), pp. 687-701.

Johnson, B. R. & Onwuegbuzie, A. J., 2004. Mixed methods of research: A reserach paradigm whose time has come. *Educational Researcher,* 33(7), pp. 14-26.

Johnson, B. R., Onwuegbuzie, A. J. & Turner, L. A., 2007. Toward a definition of mixed methods research. *Journal of Mixed Methods Reserach,* 1(2), pp. 112-133.

Jones, S. A.;, 2015. *Measuring the impact of bim on complex buildings,* Bedford, USA: Dodge Data and Analytics.

Jones, S. A., Laquidara-Carr, D. & Barnett, S., 2015. *Measuring the Impact of BIM on Complex Buildings,* Bedford: Dodge Data & Analytics.

Joslin, R. & Müller, R., 2015. Relationships between a project management methodology and project success in different project governance contexts. *International Journal of Project Management,* 33(6), pp. 1377-1392.

Jugdev, K. & Müller, R., 2005. A retrospective look at our evolving understandinf of project success. *Project Management Journal,* 36(4), pp. 19-31.

Khosravi, S. & Afshari, H., 2011. *A success measurement model for construction projects.* Singapor, 2011 International Conference on Financial Management and Economics.

Kiviniemi, A. & Codinhoto, R., 2014. Challenges in the Implementation of BIM for FM—Case Manchester Town Hall Complex. *Computing in Civil and Building Engineering,* p. 665–672.

Koskela, L., 2000. *An Exploration Towards a Production Theory and its Application to Construction.* Espoo, VTT Technical Research Center.

Koutsogiannis, A., 2019. *Artificial intelligence: The future of construction.* [Online] Available at: https://www.letsbuild.com/blog/artificial-intelligence-the-future-of-construction [Accessed 3 October 2020].

Kranz, M., 2017. *AI Business.* [Online] Available at: https://aibusiness.com/ai-brain-iot-body/ [Accessed 21 May 2020].

Kranz, M., 2017. *AI Is the Brain, IoT Is the Body.* [Online] Available at: https://aibusiness.com/ai-brain-iot-body/ [Accessed 27 March 2019].

Kymmell, W., 2008. *Building Information Modeling: Planning and Managing Construction Projects with 4D CAD and Simulations.* 1st ed. New York: McGraw-Hill Companies Inc..

Leedy, P. D. & Ormrod, J. E., 2010. *Practical Research: Planning and Design.* 9th ed. New Jersey: Pearson.

Liamputtong, P. & Ezzy, D., 2005. *Qualitative Research Methods.* Melbourne: Oxford University Press.

Liu, J., Jennesse, M. & Holl, P., 2016. *Utilizing Light Unmanned Aerial Vehicles for the Inspection of Curtain Walls: A Case Study.* s.l., Construction Research Congress.

Liu, P. et al., 2014. A review of rotorcraft Unmanned Aerial Vehicle (UAV) developments and applications in civil engineering. *Smart Structures and Systems,* 13(6), pp. 1065-1094.

Luo, L., He, Q., Xie, J. & Yang , D., 2016. Investigating the Relationship between Project Complexity. *Journal of Management in Engineering,* 33(2).

Lu, W., Lai, C. C. & Tse, T., 2019. *BIM and Big Data for Construction Cost Management.* 1st ed. Oxon: Taylor & Francis Group.

MagiCAD, 2020. *Building Information Modelling.* [Online] Available at: https://www.magicad.com/en/bim/ [Accessed 7 October 2020].

McPartland, R., 2017. *BIM dimensions - 3D, 4D, 5D, 6D BIM explained.* [Online] Available at: https://www.thenbs.com/knowledge/bim-dimensions-3d-4d-5d-6d-bim-explained [Accessed 29 May 2020].

Molenaar, K. R. et al., 2013. Construction project peer reviews as an early indicator of project success. *Journal of Management in Engineering,* 2013(29), pp. 327-333.

Molenaar, K. R. et al., 2013. Construction project peer reviews as an early indicator of project success. *Journal of Management Engineering,* pp. 327-333.

Mosly, I., 2017. Applications and Issues of Unmanned Aerial Systems in the Construction Industry. *International Journal of Construction Engineering and Management,* 6(6), pp. 235-239.

Nam, C. H. & Tatum, C. B., 1988. Major characteristics of constructed products and resulting limitations of construction technology. *Construction Management and Economics 6, 133•148.,* Volume 6, pp. 133-148.

Naoum, S. G., 1994. Critical analysis of time and cost of management and traditional contracts. *Journal of Construction Engineering and Management,* 120(3), pp. 687-705.

Naoum, S. G., 2013. *Dissertation Research and Writing for Construction Students.* 3rd ed. London: Routledge.

NBIMS, 2019. *ABOUT THE NATIONAL BIM STANDARD-UNITED STATES®.* [Online] Available at: https://www.nationalbimstandard.org/about [Accessed 7 October 2020].

Nguyen, T. A. & Chovichien, V., 2013. A PRACTICAL LIST OF CRITERIA FOR EVALUATING CONSTRUCTION PROJECT SUCCESS IN DEVELOPING COUNTRIES. *ASEAN Engineering Journal Part C,* 3(2), pp. 21-41.

O'Neill, D., 2020. *What is holding back BIM?.* [Online] Available at: https://www.pbctoday.co.uk/news/bim-news/bim-barriers/73098/ [Accessed 4 October 2020].

Ofori, G., 2015. Nature of the Construction Industry, Its Needs and Its Development: A Review of Four Decades of Research. *Journal of Construction in Developing Countries,* 20(2), pp. 115-135.

Oke, A., Aigbavboa, C. & Omole, O., 2019. *Drivers to the Adoption of Automation and Robotics in the Construction Industry.* Toronto, Proceedings of the International Conference on Industrial Engineering and Operations Management.

Ospina, S., 2004. Qualitative research. In: G. S. a. J. M. G. Goethals, ed. *Encyclopaedia of Leadership.* London: Sage, pp. 1280-1285.

Owen-Hill, A., 2017. *What's the Difference Between Automation and Robotics?.* [Online] Available at: https://blog.robotiq.com/whats-the-difference-between-automation-and-robotics [Accessed 3 June 2020].

Parfitt, M. K. & Sanvido, V. E., 1993. Checklist of critical success factors for building projects. *Journal of Management in Engineering,* 9(3), pp. 243-249.

Peansupap, V. & Walker, D., 2004. Strategic Adoption of Information and Communication Technology (ICT): Case Studies of Construction Contractors.. *Association of Researchers in Construction Management.,* pp. 1235-45.

Prabhakar, G. P., 2008. What is Project Success: A Literature Review. *International Journal of Business and Management,* 3(9), pp. 3-10.

Project Management Institute, 2016. *Construction Extension to the PMBOK Guide.* 6th ed. Pennsylvania: Project Management Institute.

Provost, F. & Fawcett, T., 2013. *Data Science for Business.* 1st ed. Sebastopol: O'Reilly Media Inc..

Qu, S. Q. & Dumay, J., 2011. The qualitative research interview. *Qualitative Research in Accounting and Management,* 8(3), pp. 238-264.

Rajagopalan , R., Hameed , T., Rajamani , B. & Sethuraman , B., 2019. *Embracing Smarter Facilities.* [Online]
Available at: https://www.cognizant.com/whitepapers/embracing-smarter-facilities-management-codex2931.pdf
[Accessed 21 May 2020].

Ranger, S., 2018. *What is cloud computing? Everything you need to know about the cloud explained.* [Online]
Available at: https://www.zdnet.com/article/what-is-cloud-computing-everything-you-need-to-know-about-the-cloud/
[Accessed 21 May 2020].

Ray, S., 2018. *History of AI.* [Online]
Available at: https://towardsdatascience.com/history-of-ai-484a86fc16ef
[Accessed 28 March 2019].

Rouse, M., 2018. *IoT Agenda.* [Online]
Available at: https://internetofthingsagenda.techtarget.com/definition/IoT-device
[Accessed 21 May 2020].

Sacks, R., Eastman, C., Lee, G. & Teich, P., 2018. *BIM Handbook: A Guide to Building Information Modeling for Owners, Designers, Engineers, Contractors, and Facility Managers.* 3rd ed. Hoboken, New Jersey: John Wiley & Sons, Inc..

Sacks, R., Eastman, C., Lee, G. & Teich, P., 2018. *BIM Handbook: A Guide to Building Information Modeling for Owners, Designers, Engineers, Contractors, and Facility Managers.* 3rd ed. Hoboken, NJ: Wiley.

Sah, V. & Cory, C., 2009. Building Information Modeling: An Academic Perspective. *Technology Interface Journal,* 136(1), pp. 30-38.

Sarantakos, S., 1998. *Social Research.* 2nd ed. Melbourne: Macmillan Education.

Sardroud, J. M., Tavasani, M. M. & Ranjbardar, A., 2018. *Barriers Analysis to Effective Implementation of BIM in the Construction Industry.* Berlin, Germany, 35th International Symposium on Automation and Robotics in Construction (ISARC).

SAS Analytics Software & Solutions, 2020. *Big Data: What it is and why it matters.* [Online] Available at: https://www.sas.com/en_us/insights/big-data/what-is-big-data.html [Accessed 8 May 2020].

Saunders, M., Lewis, P. & Thornhill, A., 2009. *Research Methods for Business Students.* 5th ed. Harlow: Pearson Education.

Schia, M. H., Trollsås, B. C., Fyhn, H. & Lædre, O., 2019. *The Introduction of AI in the Construction Industry and Its Impact on Human Behavior.* Dublin, Ireland, 27th Annual Conference of the International Group for Lean Construction (IGLC).

Scott, P. J. & Briggs, J. S., 2009. A pragmatists argument for mixed methodology in medical informatics. *Journal of Mixed Methods Research,* 3(3), pp. 223-241.

Seale, C. F., 2002. Computer assisted analysis of qualitative data.. In: F. G. a. J. Holstein, ed. *Handbook of Interview Research.* Thousand Oaks, CA: Sage, pp. 651-670.

Shang, Z. & Shen, Z., 2014. Critical Success Factors (CSFs) of BIM Implementation for Collaboration based on System Analysis. *COMPUTING IN CIVIL AND BUILDING ENGINEERING ©ASCE 2014,* pp. 1441-1448.

Sharma, R., 2017. *What is Artificial Intelligence? How does Artificial Intelligence work and how is AI used?.* [Online] Available at: https://medium.com/@raghav0278/what-is-artificial-intelligence-how-does-artificial-intelligence-work-and-how-is-ai-used-95803f7da570 [Accessed 5 October 2020].

Sheppard, M., 2004. *Appraising and Using Social Research in the Human Services: An introduction for social work and health professionals.* London: Jessica Kingsley.

Siebert, S. & Teizer, J., 2014. Mobile 3D mapping for surveying earthwork projects using an Unmanned Aerial Vehicle (UAV) system. *Automation in Construction,* Volume 41, pp. 1-14.

Silva, G. A. S. K., Warnakulasuriya, B. N. F. & Arachchige, B. J. H., 2016. *Criteria for Construction Porject Success: A Literature Review.* s.l., 13th International Conference on Business Management 2016.

Silva, G., Warnakulasuriya, B. & Aracgchige, B., 2016. Criteria for Construction Project Success: A Literature Review. *SSRN Electronic Journal*, xxx January, p. xxx .

Smith, P., 2014. BIM Implementation – Global Strategies. *Procedia Eng.,* Volume 85, pp. 482-492.

Snyder, J., Menard, A. & Spare, N., 2018. *Big Data = Big Questions for the Engineering and Construction Industry,* Denver: FMI Corporation.

Techopedia, 2020. [Online] Available at: www.techopedia.com/ [Accessed 4 October 2020].

Thomas, E. et al., 2018. *Construction Disconnected. 2018 Industry Report,* San Francisco: PlanGrid & FMI.

Travaglini, A., Radujkovic, M. & Mancini, M., 2014. Building Information Modelling (BIM) and Project Management: a Stakeholders Perspective. *Organization, Technology and Management in Construction,* 6(2), pp. 1058-1065.

Tuman, J., 1986. *Success modeling: A technique for building a winning project team.* Montreal, Canada, PMI Annual Seminar & Symposium.

United BIM, 2019. *BIM Maturity Levels Explained- Level 0, Level 1, Level 2, Level 3.* [Online] Available at: https://www.united-bim.com/bim-maturity-levels-explained-level-0-1-2-3/ [Accessed 7 October 2020].

Vian, A., Opoku, A. & Aziz, Z., 2016. *Research Methodology in the Built Environment. A selection of Case Studies.* 1st ed. London: Routledge.

Viig, O. J., 2018. *BIM as a project management tool on construction projects.* [Online] Available at: http://apppm.man.dtu.dk/index.php/BIM_as_a_project_management_tool_on_construction_projects
[Accessed 22 May 2020].

Vrijhoef, R. & Koskela, L., 2008. *A Critical Review of Construction as a Project-based Industry : Identifying Paths Towards a Project-independent Approach to Construction.* Helsinki, Technical Research Centre of Finland (VTT) / Association of Finnish Civil Engineers (RIL).

Waterhouse, R., 2020. *Tackling the BIM blockers - the three levers we have to pull.* [Online] Available at: https://www.bimplus.co.uk/analysis/breaking-bim-blockers-three-levers-we-have-pull/
[Accessed 4 October 2020].

Winch, G. M., 1989. The construction firm and the construction project: a transaction cost approach. *Construction Management and Economics,* Volume 7, pp. 331-345.

Winch, G. M., 2010. *Managing Construction Projects.* 2nd ed. Hoboken: Wiley-Blackwell.

Wong, A., Wong, F. & Nadeem, A., 2009. *Comparative roles of major stakeholders for the implementation of BIM in various countries.* Noordwijk Aan Zee, Proceedings of the International Conference on Changing Roles: New Roles, New Challenges.

Yan, H. & Damian, P., 2008. Benefits and barriers of building information modelling. *12th International Conference on Computing in Civil and Building Engineering.*

Yin, R. K., 2009. *Case Study Research: Design and Methods.* 4th ed. London: Sage.

Yi, R. & Li, M., 2018. *An Economic Analysis on Automated Construction Safety. Internet of Things, Artificial Intelligence and 3D Printing.* 1st ed. Singapore: Springer.

Zhu, J. E. et al., 2016. A Framework-Based Approach to Utility Big Data Analytics. *IEEE Transactions on Power Systems,* 31(2016), pp. 2455-2462.