AALBORG UNIVERSITY
STUDENT REPORT

Study Board of Civil Engineering
Thomas Manns Vej 23 DK - 9220 Aalborg East
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Risk Assessment of Building Information Modelling in the Construction Industry

Melinda Milbertaite

RISK4

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Co-Supervisor: Dewan Ali Ahsan

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Author

Melinda Milbertaite

Study Board of Civil Engineering
Thomas Manns Vej 23 DK - 9220 Aalborg East
www.build.aau.dk

ABSTRACT

Digitalization has become an every-day process of today's world – Building Information Modelling (BIM) is an important part of this. BIM is a technology that is used to integrate structured, multi-disciplinary data in order to produce a digital representation of an asset across its lifecycle, from planning and design to construction and operations, in some cases, throughout the demolition phase. BIM consists of such properties as the geometry of the building, spatial and geography-related information, quantities of the particular elements of the dwelling as well as budget, project schedule and inventories. The different ways of applying the BIM can be considered as visualization, fabrications/shop drawings, code reviews, cost estimating, construction sequencing, conflict, interference, and collision detection, forensic analysis, facilities management and others.

However, despite the fact that this technology may help companies or the individuals in the creation of data or information management of a variety of building or infrastructure projects, several misunderstandings and misconceptions may appear when it is either used by different stakeholders or having changes in the later stages of the projects – this may result in budget overruns as well as schedule delays. Also, the industry of construction is thought to be one of the most "conservative" one, having in mind the level of digitalization in this industry. This is why, the risk assessment related to this topic is believed to be necessary.

First of all, the risk identification is done – with a help of cause-effect analysis, four main categories of risks together with fifteen main causes are identified. The problem statement is dealt with a help of the use of various risk assessment tools to identify – Risk Matrix, Risk Heatmap. Once the severity and frequency of each cause of the risk were identified, the previously mentioned tools assisted in defining the areas of BIM that the majority of the attention should be paid to in order to avoid both overruns of the budget and schedule delays – in this case, Cost-Based risks are considered as the most vulnerable ones. For the risk evaluation, decision tree is done with the particular case assumed in order to find the best solution for the management of risks, together with the risk mitigation of possible measures. A set of various risk reducing strategies are being recommended for each of the risk category identified. It is up to every organization or company's values and goals to choose particular measures.

PREFACE

The master's thesis is done as a part of the 4th semester of the Master of Science in Technology in Risk and Safety Management at Aalborg University (AAU) in Esbjerg. The semester took place during the period from the 1st of September 2021 until the 7th of January 2022. The master's thesis is a part of the university's curriculum and is the final precondition to graduate from the earlier mentioned education.

The initial idea of the master's thesis was the risk assessment of Building Information Modelling, including Risk Identification, Risk Analysis and Risk Evaluation. It also involves the Risk Assessment of the possible measures identified before. Once the topic of this master's thesis was finalized, the aim of the research was established. The aim was to analyse whether the current system of using BIM is vulnerable or not, and what could be done to either prevent or reduce the loss in the construction project that may happen due to either incorrect or no use of BIM. This is done through the same Risk Assessment that was mentioned before. Therefore, the structure of this report is:

- Chapter 1: Introduction
- Chapter 2: Methodology
- Chapter 3: Establishing the Context
- Chapter 4: Risk Assessment
- Chapter 5: Conclusion and Discussion

The structure of this report is done in such a way that includes several components- they are believed to help the reader with understanding the thesis. To begin with, having in mind acronyms used in this report, each of them is written out the first time when it is used in the report. Afterwards, a full list of all the acronyms and the description of all is given after the "ACKNOWLEDGEMENT". Tables and figures within this report are numbered according to their own ordinal number in a proper order. The references used in the master's thesis are identified in regard to the ISO 690 style of citation. The list of the references can be seen at the end of this document in the chapter called "References".

The hand-in date is on the 7th of January 2022. The oral defence is expected on the 26th of January 2022. Once both the written master's thesis and the defence are successfully completed, the graduation of the MSc Risk and Safety Management is certain.

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ACRONYMS AND KEYWORDS

Acronym	**Meaning**
3D	Three – Dimensional
AAU	Aalborg University
AE	Architects, Engineers
AEC	Architecture, Engineering and Construction
BIM	Building Information Modelling
CAD	Computer-Aided Design
EMV	Expected Monetary Value
GFRM	Generic Framework of Risk Management
HVAC	Heating, Ventilation and Air Conditioning
ICT	Information and Communication Technology
IM	Information Management
ISO	International Organization for Standardization
MEP	Mechanical, Electrical and Plumbing
MGI	McKinsey Global Institute
PM	Project Management/Manager
UK	United Kingdom

Keywords

RISK ASSESSMENT | CONSTRUCTION | BUILDING INFORMATION MODELLING | DIGITALIZATION | RISK IDENTIFICATION | RISK ANALYSIS | RISK EVALUATION | MEASURES | STANDARDS | COMPUTER-AIDED DESIGN |

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1. Introduction

Digitalization has become an every-day process of today's world – every individual, a group, an organization or a company should be adapted to the digitalization due to its exponential growth. (1) There are new developments appearing every day – from various e-business applications such as e-government public sector, and logistics and value chain to artificial intelligence tools such as virtual reality or three - dimensional (3D) printing. (1) It is believed to assist in both personal and business-related tasks – this may alter the way the relationship between human beings and computers is perceived. (1) However, despite being one of the biggest ones, the industry of construction is also thought to be one of the most "conservative". (2)

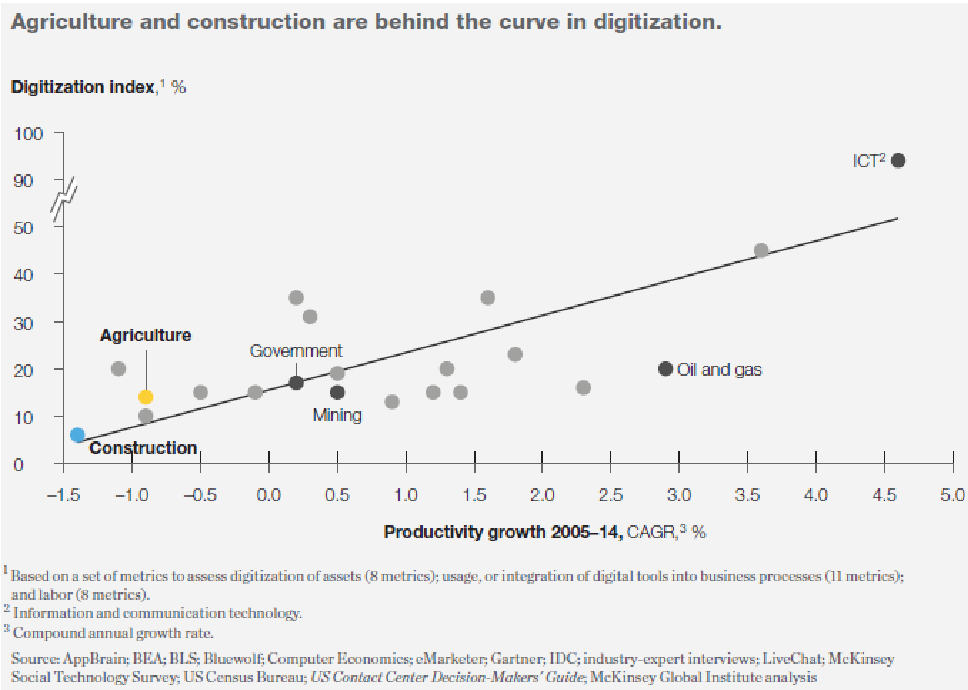

Figure 1 Digitalization Index and Productivity Growth in Various Industries (3)

Research done in 2018 regarding the future of high technologies in both agriculture and construction industries showed that considering the index of digitalization, the latter industry is left behind compared to, for example, Information and Communication Technology (ICT), that reached the index of more than 90% at that time (3) (Figure 1). As the demand is getting higher for the construction, so is the need for the related technologies – they are supposed to increase the productiveness of this business. (4) The more advanced level of the productivity in the construction industry may lead to bigger amounts of projects done, therefore, better quality of life and infrastructure in general. Nonetheless, in order to do so, much more attention should be paid to the digital technologies – analysis done by the McKinsey Global Institute (MGI) showed that the improvements in the implementation of the technology in the construction field can result in approximately 14-15% more efficient productivity as well as around 4-6% of cost savings. (4)

Building Information Modelling (BIM) has turn out to be a well-known technology in the industry of architecture, engineering and construction (AEC), that is still developing. (5) According to Autodesk, BIM is “the holistic process of creating and managing information for a built asset”. (6) “Based on an intelligent model and enabled by a cloud platform, BIM integrates structured, multi-disciplinary data to produce a digital representation of an asset across its lifecycle, from planning and design to construction and operations”, in some cases, even throughout the demolition. (6) Through a virtual 3D model, BIM may be recognized as a virtual process that includes various systems and aspects, and allows the successful and efficient collaboration among all the team members (for example, owners, architects, engineers, suppliers and other) compared to the traditional way of working in the construction industry. (7) In certain circumstances, BIM may be also represented as “building information management” or “building information marketing”. (8) Nevertheless, the report focuses on BIM as a “Building Information Modelling”.

Most of the time, it consists of such properties as the geometry of the building, spatial and geography-related information, quantities of the particular elements of the dwelling as well as budget, project schedule and inventories. (7) Such pieces of BIM software as Autodesk Revit, ArchiCAD, AutoCAD and others are believed to be the most used ones (Figure 2). (9)

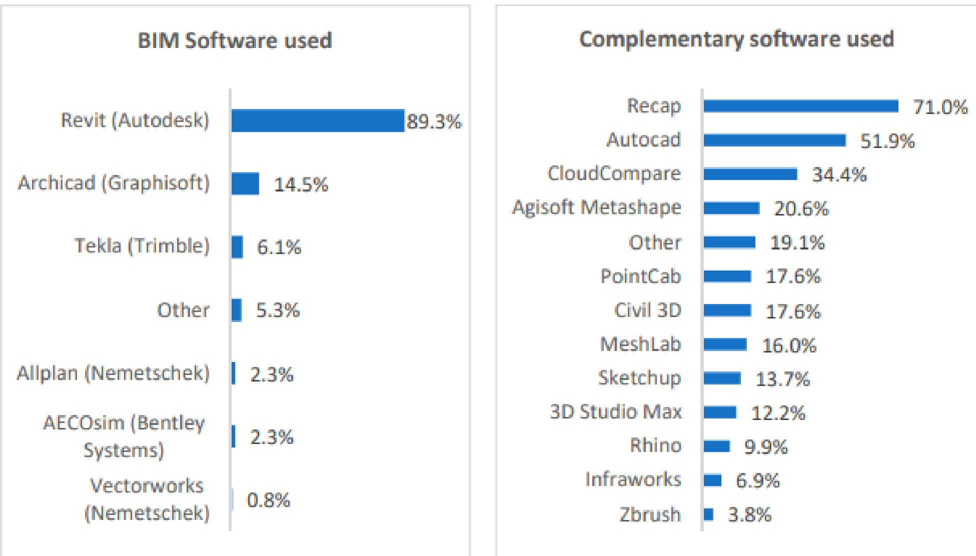

Figure 2 Digital and Complementary Tools Used in BIM (9)

BIM was invented as a former combination of computer-aided design (CAD), AEC technology and Information Management (IM) which were the basis for 3D modelling in the late 1990s. (10) However, other sources have the evidence of formulation of BIM dating back to 1972-1974, when "Sketchpad" was used - much earlier before the release of AutoCAD. (11) Since those times, BIM has evolved into a tool of every-day-use of AEC that does not only own a part of software, which allows the spatial modelling with the contribution to the information, but also tools and various methods related to the project management (PM). (12) The different ways of applying the BIM are (7) (Figure 3):

- Visualization
- Fabrications/Shop Drawings
- Code Reviews
- Cost Estimating
- Construction Sequencing
- Conflict, Interference, and Collision Detection
- Forensic Analysis
- Facilities Management

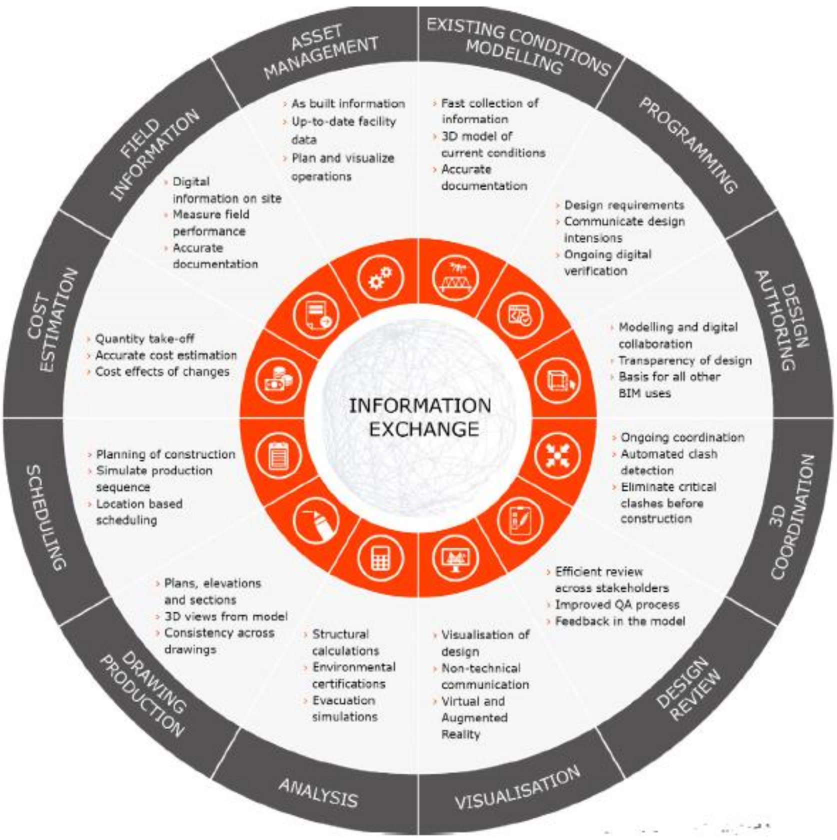

Figure 3 BIM Uses Identified by Consulting Engineers (13)

As it was mentioned before, BIM can be used in the different phases of each project (Figure 4) – from the early conceptual planning phase to the start-up and operational phase. (14) This way, different parties/stakeholders are integrated into the project life cycle throughout every phase of it and collaborating in order to optimize the schedule, control and save the costs. (7) Other advantages of BIM can be considered as (7) (15) (9) (Figure 5):

- Accurate Representation of the Model (Visualisation)
- Analysed and Improved Designs (Quality Control)
- Easy-to-Share and Transfer Data (Data Integration)
- Monitoring and Assessment
- Precise Quantities for Materials and Components Involved

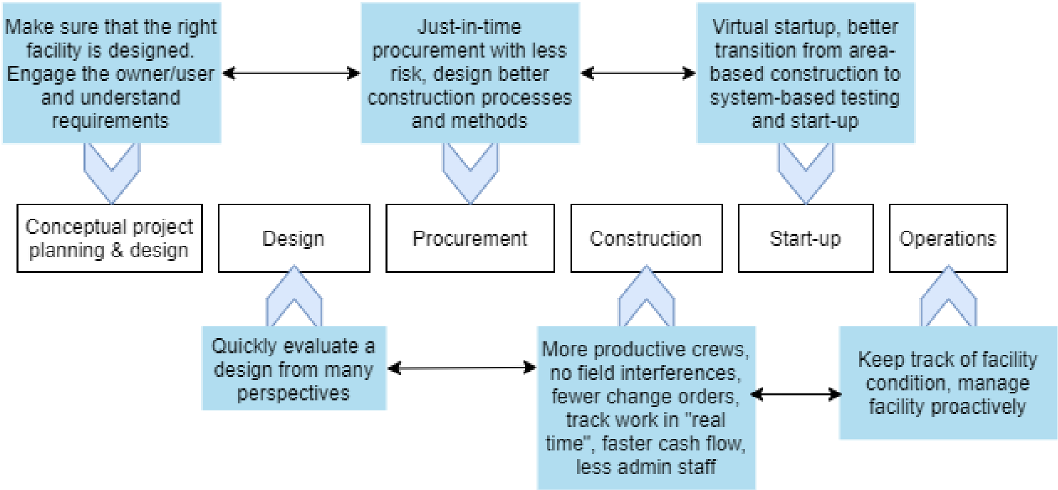

Figure 4 BIM Applications in the Different Phases of an AEC Project (14)

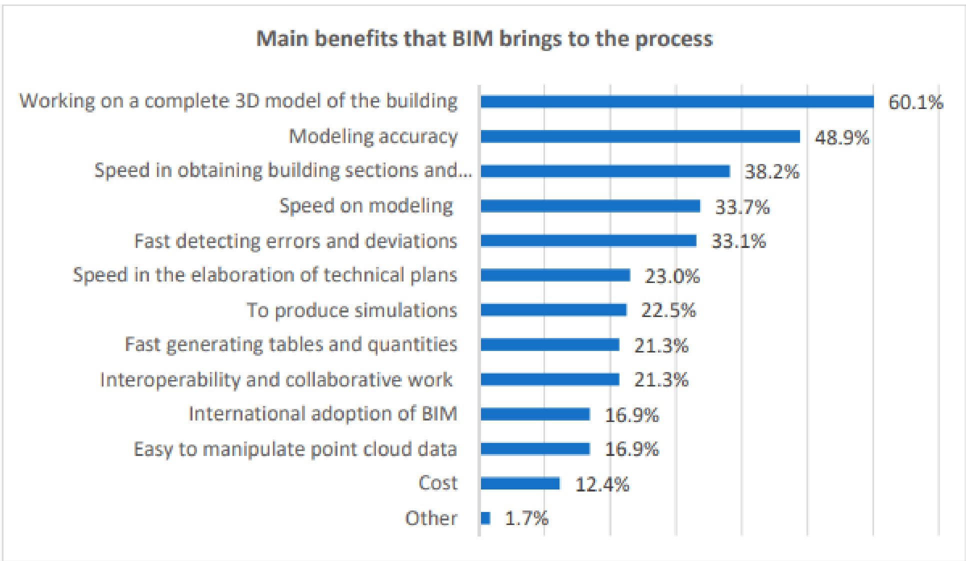

Figure 5 Main Benefits of BIM (9)

Once the project is done, the model done with a help of BIM itself often consists of the accurate geometry, data necessary to the processes related to design, procurement, production and construction, later – for operational and maintenance works. (7)

In 2018, International Organization for Standardization (ISO) has also published a standard considering BIM - ISO 19650 - *Organization and digitization of information about buildings and civil engineering works, including building information modelling (BIM) – Information management using building information modelling.* (16) It covers such aspects as concepts and principles, delivery and operational phases as well as security minded-approach in regard to using BIM. (16) The standard is made based on the standards of management of BIM information established in the United Kingdom (UK) (BS 1192). The creation of such a standard is believed to help to use BIM in the broader context, consequently assisting in the efficiency of various construction projects. (16)

Nevertheless, despite all the pros this technology has that helps companies or the individuals in the creation of data or information management of a variety of building or infrastructure projects, several misunderstandings and misconceptions may appear when it is either used by different stakeholders or having changes in the later stages of the projects. Therefore, risks related to them can become evident too.

1.1 Scope

The purpose of this project is to do the risk assessment of BIM in various construction projects. For this, the Generic Framework of Risk Management (GFRM) model is proposed, and one of it mainly focuses on the assessment of the risks and tasks within the risk management. Using the model and the proposed methodology, it is also necessary to determine the system that is going to be analysed in the thesis, to delimiting the analysis only to the particular stage. Afterwards, the risks related to the topic chosen were identified. The identified risks were categorized and systematized using the Ishikawa diagram (also known as Fishbone). The next step of the model is the analysis of the risks, in which their frequency, severity, and impact in the construction field were defined and analysed. Once the level of severity and impact that the risks present have been analysed, the risk evaluation as well as the response management is proposed – specific recommendations and strategies are identified as the possible measures. Finally, the conclusion and discussion of the report are presented.

1.1.1 Problem Formulation

The project analyses Risk Assessment in the Building Information Modelling following the GFRM as a basis in order to define and identify the risks, analyse the potential causes and evaluate the risks using particular tools learnt during the master's studies as well as suggest the possible risk mitigation strategy. Therefore, with a principal focus on the BIM risks that may have an effect on the construction industry (having in mind the construction of both buildings and infrastructure), the following problem statement is defined:

Assessment of the potential risks of BIM in the construction industry that may have an impact on both budget and time schedule of the project

It was decided to focus on both budget and time schedule of construction projects because of the strong connection between these two aspects – it is believed that the budget depends or may vary having in mind the changes in the time schedule, or vice versa. Once the previously mentioned steps are achieved, it is necessary to review the process of risk assessment and update it if necessary. This leads us to a sub-statement of the problem:

Assessment of the precautions taken in order to prevent potential risks of BIM from happening

1.2 Basis

The main ideas and inspiration for the risk assessment in regard to BIM are collected from a few types of sources. First of all, despite the author of the thesis having a background that is mostly related to AEC and BIM, a number of topic-related literature is investigated in order to present the report in a professional way (for instance, *BIM-Based Collaborative Building Process Management* (11) or *Building Information Modeling: Why? What? How?* (17)). Then, with an assist of different reports and articles concerning advantages as well as risks, a system is identified with the boundaries and limitations of BIM being analysed – especially the ones with the particular examples of given building projects to be able to compare the statistics and data provided (to give an example, *Building Information Modeling (BIM): Trends, Benefits, Risks, and Challenges for the AEC Industry* (7)). For the Risk Analysis and Risk Evaluation parts of the report, such tools as *Cause-and-Effect Analysis, Risk Matrix, Heat Map* and *Decision Tree* are applied. Moreover, the courses presented at the university have been very useful, taking into account the process of designing the thesis (the structure of the report) and solving the matters (tools selected from the courses learnt on this study programme) related to the topic chosen.

1.3 Limitations

The report has some limitations that are going to be presented. First of all, the majority of studies and researches were published between the year of 2005 and 2015, with some of them being published later. Despite the fact that this topic is rather new and the risks related to it may still appear, the lack of the newest data may have caused some doubts. One of the presumptions could be considered the fact that the level of implementation and use of BIM differs in various countries – particular countries are bearing the same risks of this technology that others may have faced 10 years ago. This is believed to make the work on this report slightly more complicated. Moreover, another presumption could be related to the current circumstances – the pandemic, that has been lasting for almost two years, could have suspended the scientific work related to BIM, thus, the number of studies done towards this topic has noticeably decreased in the past few years.

The last limitation is related to the time restrictions and the scope of this document as a project of the last semester of master's studies. The process of the thesis is carried out throughout the autumn semester 2021, with a completion date of January 7th 2022. As this topic is believed to be a rather wide one, it is likely that this period is not adequate enough to identify all the aspects of the project and its construction in a more profound way – this can be done as further research in the future if needed. On the other hand, choosing one particular case in regard to the topic was thought to make the topic and the report itself too narrow due to the lack of data. Therefore, the decision of investigating the topic in general was made.

2. Methodology

In this chapter, the methodology of the master's thesis is explained – procedures applied for the research of the problem are clarified. The methodology of this report mostly focuses on the methods for the collection of data as well as its analysis and validity.

2.1 Data Collection

Considering the topic of the master's thesis, a method of data collection was chosen. It is considered as a main method for this report in order to collect and analyse the information found. There are two types of data collection – primary and secondary. (18) Primary data collection is defined as the one "collected from the first-hand experience and is not used in the past" whereas the secondary data collection is "the data that has been used in the past". (18) Due to time limitation of the thesis, secondary data collection is taken into consideration.

With a help of the available literature, various BIM- related studies and archival researches are found with a number of surveys analysed – most of the time, surveys of the people working in the construction industry and the challenges, risks and barriers they are facing. These studies have both qualitative and quantitative data that may be necessary for the problem research identified before in this report. This is expected to make a general insight of the industry to the BIM.

2.2 Data Analysis and Validity

The data collection is done together with the validity process. Even though it may be difficult to verify the validity of the information that has been collected with a help of secondary data collection method, the resources of scientific work were collected through reliable databases to ensure that the insights in regard to the topic of this report are as accurate as possible.

Moreover, as a part of the education achieved in this educational institution, for the process of data analysis and validity, a peer group of two students of MSc Risk and Safety Management in AAU participated. With a help of constant consulting meetings among the peer group chosen, a necessary professional and emotional support was received as well as feedback regarding the process of this report. Such a procedure throughout the semester believed to help to motivate on the thesis as well as make particular decision- making in various report-related circumstances.

3. Establishing the Context

3.1 System Identification

Before Risk Analysis, the system is thought to be analysed. Therefore, the system identification considers the stakeholders and decision-makers as well as the boundaries that may be present in the system. Defining the essential characteristics of the system will allow interacting and analysing risks without leaving the identified framework.

The system for the Building Information Modelling presented below seeks to identify the stakeholders that may have an interest and impact on the area defined and analysed.

3.1.1 Stakeholders

- **Owners** – as the main stakeholder, the owner is thought to hold a number of objectives that BIM is expected to have an impact on – for instance, at the beginning of the project (design stage), various options of the project may be analysed and compared, thus the cost and time estimations are believed to be more precise. (19) Moreover, there is a possibility that the owner makes the most out of the profit by optimizing the project while using BIM – digital models may help to avoid the errors as well as make some predictions in regard to the costs. This is why it is believed for this stakeholder to have a rather high interest in the implementation and use of BIM. (19)

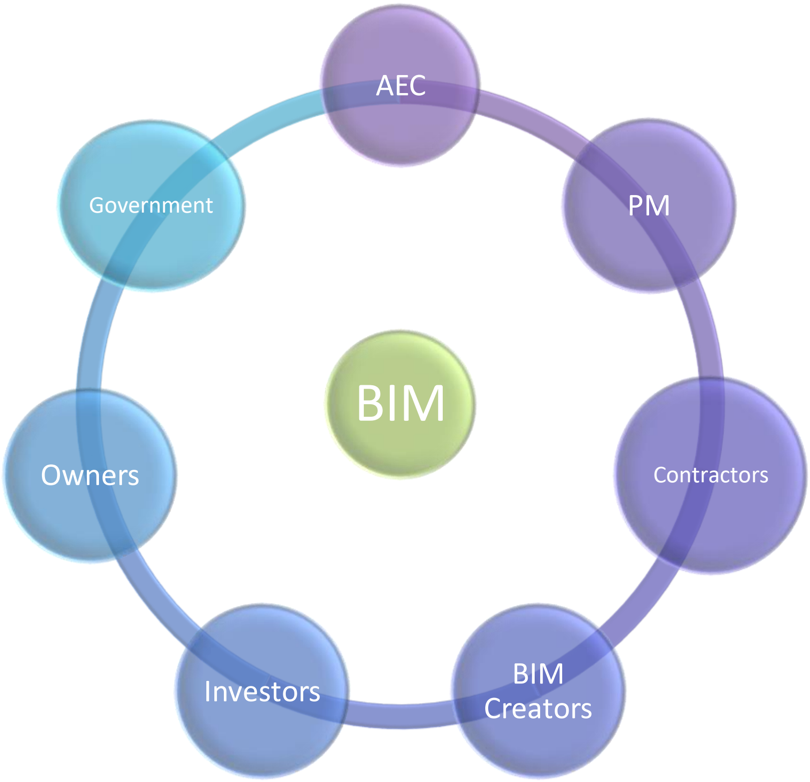

Figure 6 BIM Stakeholders (Author's Model)

- **Investors** – likely, the objectives of the people investing in BIM are the same ones despite the field they invest in - to achieve both growth and income. (20) As "the development of BIM systems responds to business needs, value proposition and the demand for return on investment", (8) it is believed that investors are having a particular level of interest towards the both implementation and use of BIM as well as its efficiency in the construction industry. (8)
- **Architects** – can be considered as one of the main stakeholders in regard to the use of BIM in this industry – according to the survey done in the United States in 2008, 43 percent of the architects being interviewed applied BIM on more than 60 percent of projects they had worked with. (7) For a comparison, in 2020, more than a decade later, 73% of design professionals are both aware and using BIM in the United Kingdom – having in mind 13% in 2011 (21) (Figure 7). The majority of the architects are aware of BIM and understand the

importance of this technology in the field they are working in– taking into consideration the productivity, improvements of the projects and higher chances of winning the projects. (7)

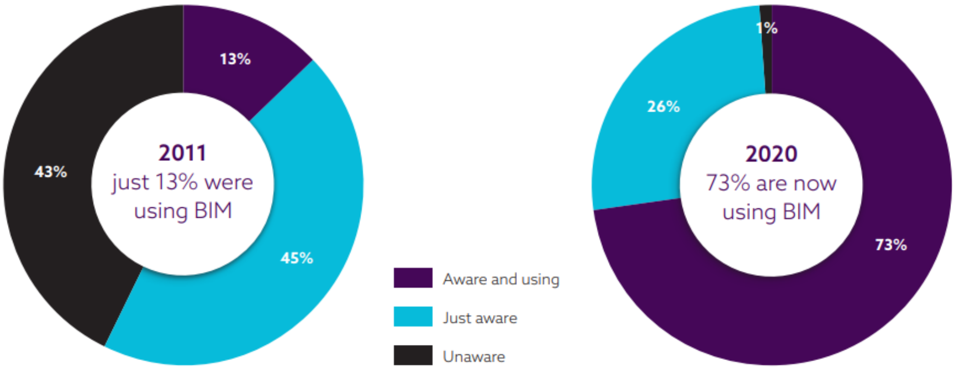

Figure 7 BIM Awareness and Use - 2011 and 2020 (21)

- **Engineers** – these stakeholders are mainly responsible for the design stage, having in mind structural, mechanical, electrical, ventilation and heating aspects (MEP, HVAC) as well as the construction phase. As the collaboration among AEC is necessary during any kind of project, engineers, as well as other stakeholders are expecting to share the work between each other – "the significance of BIM workability within the AEC industry as a key driver towards successful BIM adoption". (15) BIM is believed to assist in keeping up to the newest updates and changes of the project, thus with the help of it, the control of the information and constant evaluation is expected to be received (15) – therefore, the interest and impact of this stakeholder group is thought to be rather high.
- **Constructors** – usually, they make sure of the entire project itself in general – including the workers, their safety and duties, the process of the project. (22) Being a part of AEC, there is a need for constructors to use BIM, thus collaborate with both architects and engineers, in order to ensure the critical review considering the project.
- **Project Managers** – as project managers are most of the time in charge of such aspects as planning, execution, monitoring and control of the project, BIM can therefore be an essential part of their work – BIM provides with various estimations and quantities (cost, time, resources). (15) It might be extremely significant in the planning part as it also helps to detect various inaccuracies before particular phases of the project. (15)
- **Contractors** – as a stakeholder, they are crucial in promoting the implementation of BIM. It is because of them being responsible for "operationalising design projects". (15) - contractors may have an impact on BIM technology applications being either fully utilized or not throughout the building design, construction and maintenance phases. (15)

- **BIM Creators** – this stakeholder group is mostly accountable for creating tools and software that meet the current needs of AEC – for instance, structural, mechanical, architectural support for the companies as well as software care. As the size and the complexity of the projects are growing, it is believed that the companies belonging to the software industry may have to evolve even more and develop the existing BIM technologies in order not to fall out of the market. (8)
- **Government** – the governments of different countries (in this report, most of the time the European countries are considered) have often been interested in BIM. To give an example, one of the first countries to adopt BIM was Finland – in 2007, it was decided to make a requirement of integrated model-based operation of BIM level 2 in the future projects. (23) As a result, thanks to such a regulation, approximately 70% of the projects in Finland were managed and developed using BIM technology in 2013 whereas the awareness of it achieved the majority of the related parties (90%). (23) Rather similar case has been observed in Norway, where the requirement to use BIM in the projects was made in 2010. (23) In order to reduce the costs of public sector, the government of the UK instructed that all the governmental public projects should have followed the same BIM level 2 by the year of 2016 – this sums up that a vital impact of the various governments can be recognized in regard to the use of BIM in construction projects. (23)

3.1.2 Decision Makers

To define the system in regard to BIM, it is significant to realise which individuals or groups take part in the process of decision making.

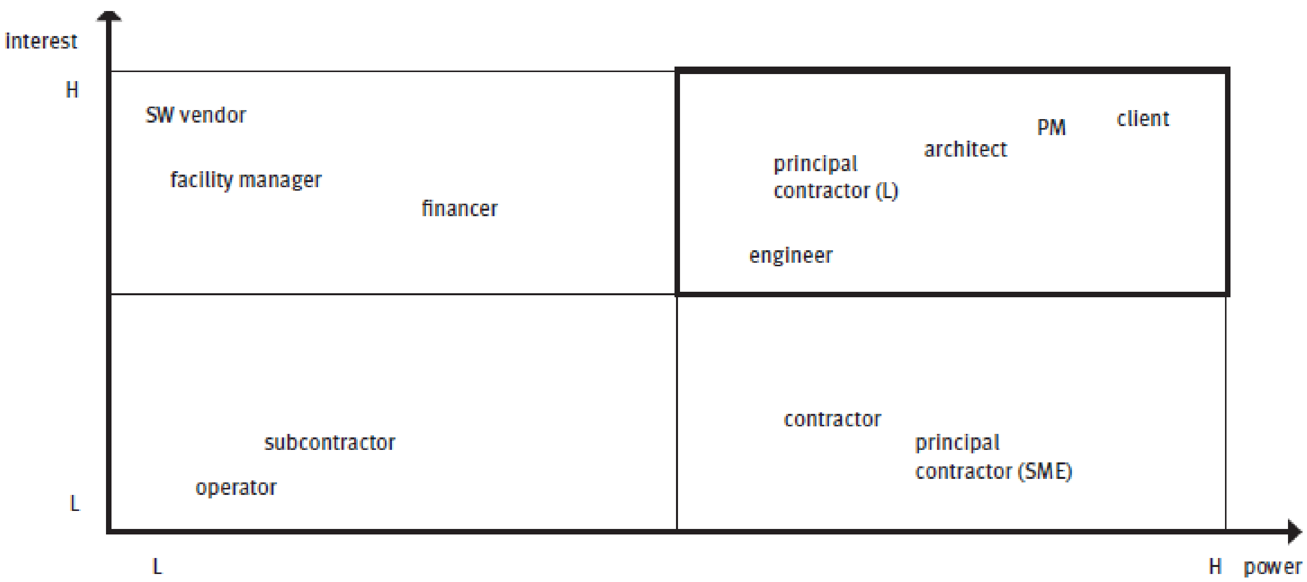

Figure 8 Interest - Power Matrix (23)

Decision makers are understood as one or more individuals having the power to make decisions and taking the responsibility for all kind of consequences related to it. The decision is based on the personal preferences among various alternatives of the decision maker himself/herself. It is thought that a decision maker may use different priorities while weighing the consequences of probable decisions. (24)

In 2014, the study "*Building Information Modelling (BIM) and Project Management: a Stakeholders Perspective*" was done in order to classify the stakeholders and define their role having in mind BIM adoption. (23) As a result, an interest-power matrix was created (Figure 8). It is a mapping model used to categorize stakeholders – it is believed to visualize the stakeholders' impact on the project and its implementation by analysing the communication and relationships in-between. (25) The matrix was put together by investigating into two main questions: (25)

- "How interested is each stakeholder group to impress its expectations on the project decisions?"
- "Do they mean to do so? Do they have the power to do so?"

Having in consideration the study mentioned before, it was found out that, in the case of BIM adoption, the ones possessing the highest power are thought to be PM, the client, architect, principal contractor and engineer. Among them, the client is the stakeholder having both the highest power and interest – according to the researchers, the client is assumed as the owner, thus having the majority of the power and the interest to benefit from the project is understandable. (23) Another stakeholder being close to the client is PM – the amount of power and interest PM has can be explained by the fact that he/she is considered to be a representative of the client and have sufficient knowledge regarding BIM. (23) The other stakeholders located in the same "high power/ high interest" area – architect, contractor, engineer – are also thought to be rather important stakeholders, however, the general position of them in the matrix is expected to be lower (most of the times, due to their lower interest or power in gaining the profit). (23) To conclude, this matrix shows that , in some cases, because of the financial and other types of potential benefits, the client (or the owner) is thought to be the main decision maker having in mind the promotion and adoption of BIM. (23)

3.2 Boundaries

Different types of boundaries are recognized in the system identified. Some of the barriers may contribute to the uncertainties that can result in the particular risks if not considered. In this report, boundaries related to the implementation, adoption as well as the use of BIM are going to be analysed.

3.2.1 Costs

To be successful in such an industry nowadays, it is necessary to invest in BIM – especially taking into consideration the government of those countries who legislated BIM. In order to fully implement BIM in each of the company, it demands costs. It usually consists of expenses related to the software, hardware and staff training. It could also be understood as the additional costs for updating the current software too. (26) As it is considered as a relatively expensive technology to implement, it is believed to be one of the main boundaries, especially for the smaller or newly-established companies facing financial challenges. (27)

3.2.2 Culture

In the case of this report, work/organizational culture is considered. The implementation of BIM may require some changes among the personnel, thus having an impact on the existing work culture. (27) This can become a barrier if the staff is not flexible enough, meaning the people working in the company are not willing to accept the new technology and apply it in their every-day's life – a social resistance is expected to happen. (26)

3.2.3 Legal

There are a few legal-related boundaries of BIM. The first one is connected to the rights of the intellectual property (IPR) done using BIM. There are some obvious disagreements towards the ownership of such property – both designers (architects) and the owners of the projects cannot agree on whom it should belong to. (27) Fortunately, some of the countries are on their way to solve this boundary. (27) Another boundary investigates the collaboration using BIM – occasionally, when different parties of the project are participating, no responsible individual is defined, therefore, particular risk management issues may arise. (28)

3.3 Physical Characteristics

BIM is a versatile virtual way of representing a model of built facility with a shared piece of information related to it. (17) A BIM model usually consists of such aspects as 3D geometry of the dwelling and its components as well as "non-physical" objects, for instance, space, zones, structure of the project or schedules (Figure 9). (17) Most of these aspects are done in a specific level of detail and includes such information as the type of the component, material, technical characteristics, preliminary costs, how the components connect between each other and others. (17)

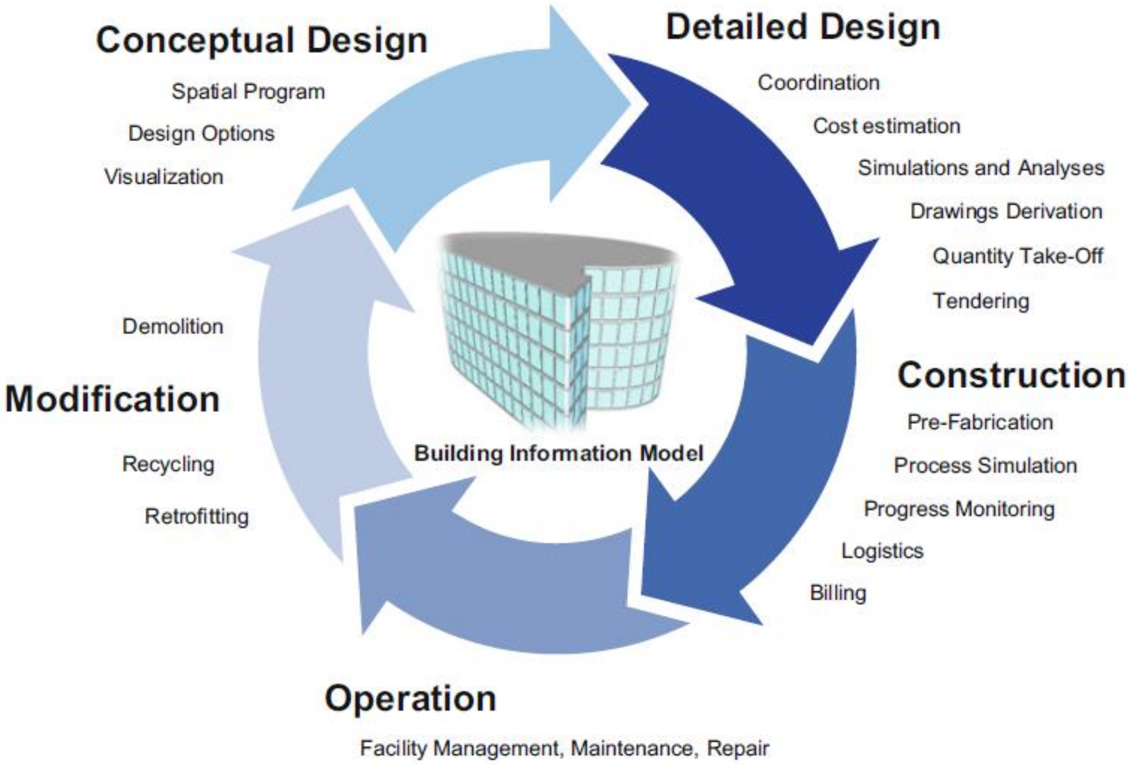

Figure 9 The Concept of BIM (17)

According to the book *"Building Information Modelling: Why? What? How?"*, the main characteristic of BIM is the ability of creating the 3D geometry of the particular facility throughout design and construction phases. (17) This way, BIM provides the foundation for the creation of clash detection in both horizontal and vertical key junctions of the dwelling. (17) Clash detection can be defined as "the technique of identifying if, where, or how two parts of the building (e.g., plumbing, walls, etc.) interfere with one another". (29)

Another significant characteristic of BIM is to be able to pass on the semantics, having in mind that every building component (for example, a wall, floor, window, roof) of BIM model has a meaning identified in the form of properties and the relation with other parts of the dwelling. (17) However, the set of data defined with a help of BIM usually depends on the type of the project and the purpose of the 3D model created. (17) That is why, no strict list of the "must-provide" information is stated when it comes to this technology. (17) In some cases, BIM is used to create a number of models of the same building with different data adopted. (17)

4. Risk Assessment

According to ISO, risk assessment is described as "the overall process of risk identification, risk analysis and risk evaluation". (30) Within this chapter, the risk assessment of the problem statement of the master's thesis is focused on. With the help of various tools mentioned in methodology, the report is expected to be guided to the right direction. The chapter consists of the following sub-chapters:

1. Risk Identification
2. Risk Analysis
3. Risk Evaluation

4.2 Risk Identification

The first step of risk assessment is considered to be risk identification. According to the ISO, risk identification is mainly done in order to "find, recognize and describe risks that might help or prevent an organization achieving its objectives". (30) It is necessary to mention that, in this step, it is significant that the latest, most relevant and eligible piece of information is collected. (30) Most of the times, when construction or engineering projects are taken into consideration, the risks related to time, cost and quality are identified. (31) However, slightly different categories of risks can be defined when thinking of BIM and its possible negative impact on previously mentioned type of projects (both budget and timeline/schedule). Those are identified as:

- Legal Risks
- Technical Risks
- Cost-Based (Financial) Risks
- Management Risks

4.2.1 Cause-Effect Analysis

Initially, as it was mentioned previously, the analysis considers four categories of risks. Therefore, the risks will be identified and ordered according to these categories. For this, Cause and Effect analysis is going to be applied (Figure 10). Cause and Effect analysis (also known as Ishikawa or Fishbone Diagram) is a technique that is supposed to assist in the identification of probable causes of the problem defined – this way, it is believed that the main causes can be detected in the early stage of the project and help in the problem-solving afterwards. (32)

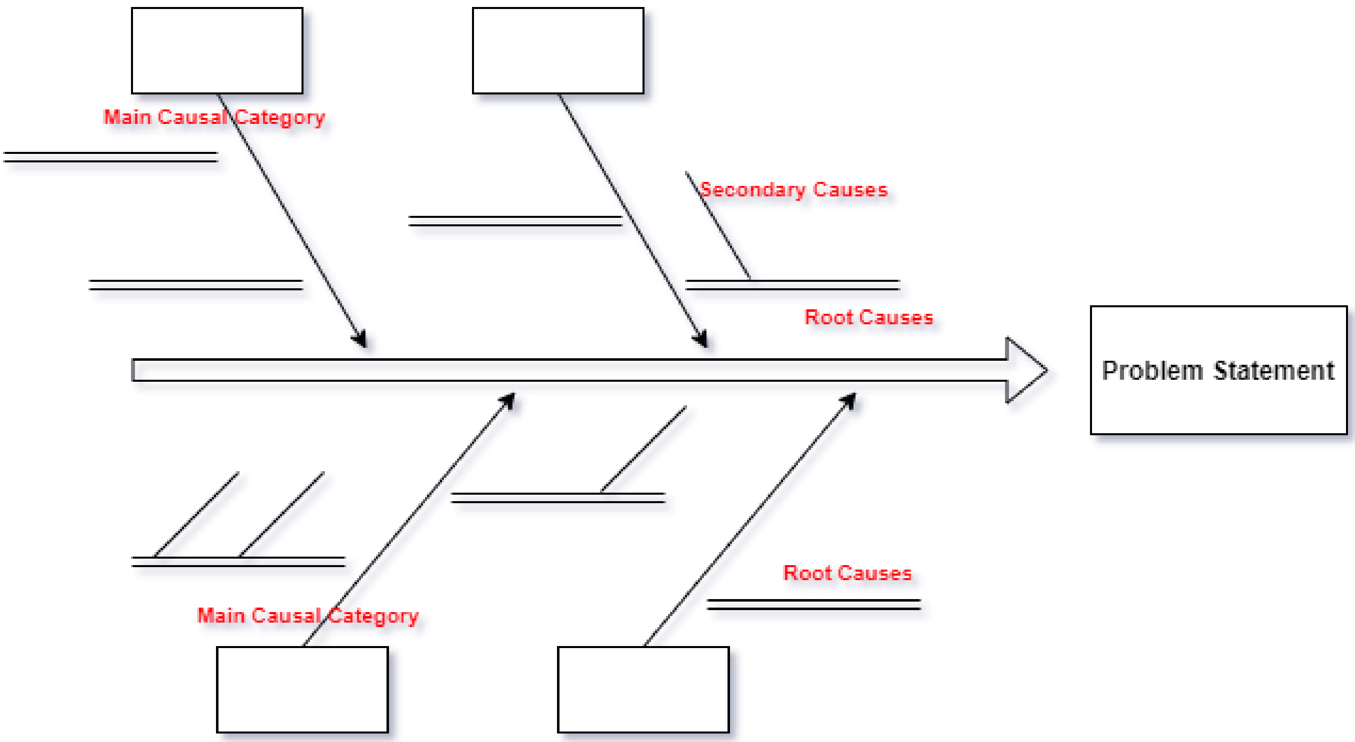

Figure 10 Concept of Fishbone Diagram (Done by the Author)

Based on the diagram, the *main causal categories* are going to be defined – the same four risk categories formerly mentioned that determine the BIM causes that may have an impact on the budget and timeline of construction projects. This follows the *problem statement* of the report. Then, each of the category is going to have *root causes* of each of the category proposed – the horizontal lines of the diagram are going to explain the causes of each of the *main causal category*. Afterwards, some *secondary causes* may be expected coming from the *root causes* – the repeated process of finding the causes. This is continued as long as all the necessary causes are found, thus the most significant or likely ones are pointed out.

The final full cause-effect analysis can be seen below (Figure 11). With a help of methodology done, four risk categories identified were used as *main causal categories*. They directly refer to the *problem statement*, which, in this case, is defined as "budget overruns/schedule delays". Every risk category has its own causes, which are defined as *root causes*. Additional *secondary causes* (the reasons why the latter ones may have appeared) were referred to some of the *root causes*. Every category of risks, with its root and secondary causes are going to be separately analysed further in this chapter of the report.

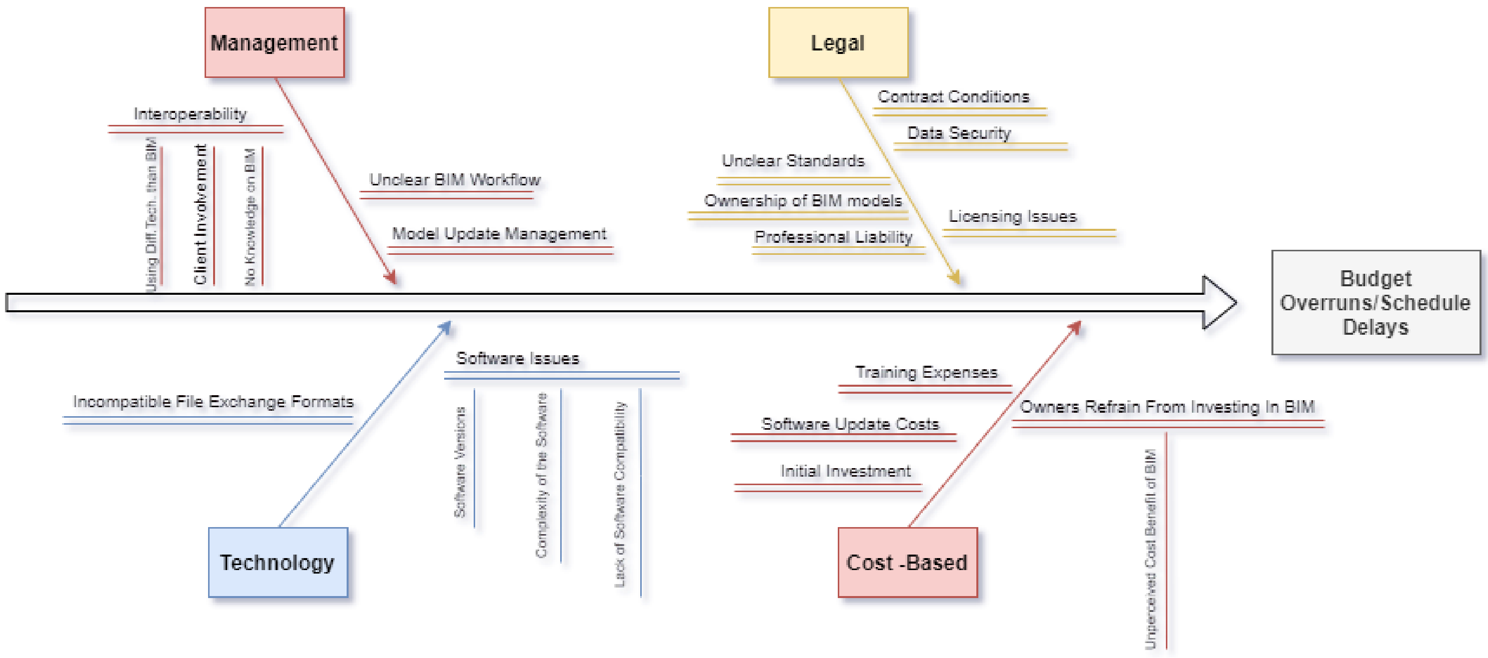

Figure 11 Cause – Effect Analysis of BIM (Author 's Model)

Technology Risks

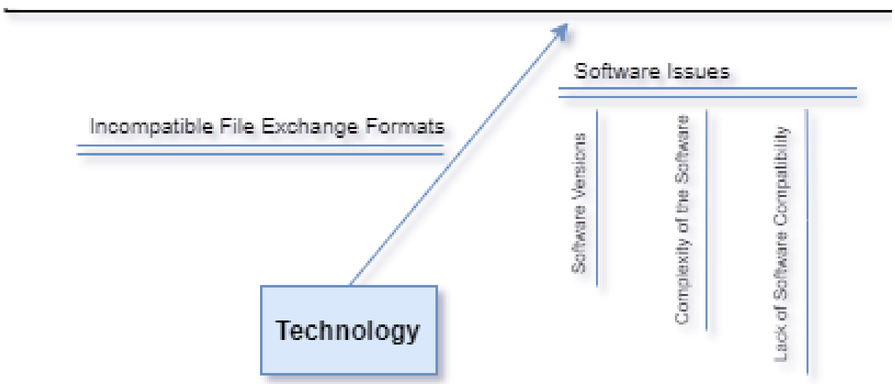

Figure 12 Technology Risks of BIM (Author's Model)

Technology risks are the ones related to "involving or needing special skills or knowledge, especially in science or engineering". (33) In the case of this report, technology risks related to BIM software are focused on, thus risks as *Incompatible File Exchange Formats*, *Complexity of the Software*, *Lack of Software Compatibility* and *Software Versions* were investigated (Figure 12).

The first technology risk to be studied is *Incompatible File Exchange Formats*. The risk may happen when specific files are updated while working on different formats of files. (34) This may also occur when using different software on the same project (for example, two companies using different software are in charge of the same project). Consequently, loss of information and miscommunication are expected. (34)

Various kinds of *software issues* happen when it comes to BIM. To begin with, *complexity of the software* can make it more complicated for the companies to implement, adapt and use BIM. It is known that different tools of BIM software are interacting between each other in a complex way that is non-intuitive. (34) Therefore, the stakeholders working on this field are concerned about the amount of time it takes to adapt such technology in order to be able to do the proper information management. As a result, files of different formats appear that makes it difficult to track and follow the latest data between different stakeholders (for example, an architect and project manager). (34)

Different *software versions* is an another BIM – related software risk that the industry has been facing lately. (34) The software developers have not realized the importance of construction processes, this is why such an issue still exists – the files created using the newest version of the specific software simply cannot occur together while using the older version of the software (to give an instance, a 3D model made using Autodesk Revit 2019 cannot be opened in Revit 2017). (34) This may lead to *lack of software compatibility* and becomes a high risk considering multiple users working on the same project while actually owning the different version of the exact software. (34) The software being incompatible can be also a result of attempting of use of software in different platforms. Depending on availability of each of the stakeholder that is working on the project, their location (whether it is an office or a construction site), various software platforms may be accessed to, thus making the collaboration in between each of the impacted-party problematic. (34)

Legal Risks

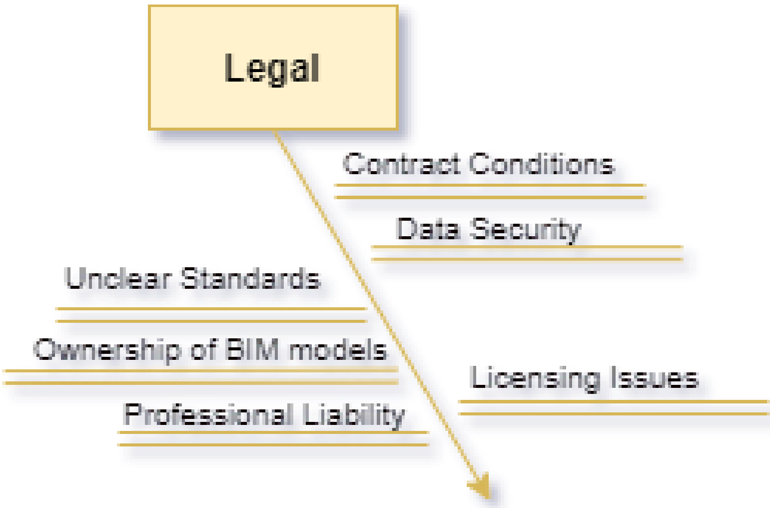

Figure 13 Legal Risks of BIM (Author 's Model)

Legal risks are believed to be the ones connected with or allowed by the law. (35) In the case of this report, such legal risks as *unclear standards*, *ownership of BIM models*, *professional liability, contract conditions, data security* and *licensing issues* were investigated (Figure 13).

One of the most common legal risks may be related to the *ownership of BIM models.* This can also be named as intellectual property – a creation of the intellect of human being that is protected and prevented from the use of others by particular laws. (36) The risk may appear when either the property is not protected well or the actual creator is not defined – to give an instance, there might be misconceptions regarding the ownership of 3D model between the owner of the project and AEC. (7) Despite the fact that the latter ones may have directly worked on the model itself, the owner may feel accredited enough to have the intellectual property himself/herself – thus, the copyright issues may happen. (7) Depending on each of the project, the ownership may vary depending on the agreements done by the company and the clients. (7)

In 2019, a study *Contractual Risks of Building Information Modelling: Toward a Standardized Legal Framework for Design-Bid-Build Projects* was done. The purpose of the study was to identify the contractual and legal risks in the implementation of BIM, review the existing BIM-related types of contracts and suggest mitigations strategies. (5) 14 risks were found, among which – *Intellectual Property.* (5) After the qualitative assessment was done in the research, intellectual property was found to be the leading one, having the highest risk and impact on BIM projects. (5)

Another legal risk is connected to *unclear standards*. It means that there are barely any contracts or standards fully operating in regard to BIM. (5) Even though ISO has published the standard for BIM in 2018 (BIM - ISO 19650 - *Organization and digitization of information about buildings and civil engineering works, including building information modelling (BIM) – Information management using building information modelling*), it is still believed to be rather new one, therefore, not applied by the majority of BIM users. Moreover, there are a few existing contracts that include some of the risks and are a great foundation for the future developments (for example, *AEC BIM Protocol, CIC BIM Protocol* or *Consensus DOCS 301 BIM Addendum*) (5). Nevertheless, not even a single one of them covers all of the main BIM risks – this is why there is still a need for a more developed contract of a broader range having into consideration BIM and construction industry in order to make the process of using BIM in the projects more efficient. (5)

Legal risks of BIM are also linked to *contract conditions* of each of construction project. Issues related to the structure of BIM contracts and its instruments have been recognized. (37) Usually, contracts involve the level of responsibilities of every project team member, but it was recognized that commonly-used traditional contracts are outdated due to either not having BIM protocols included or having them as a tiny part of a contract. (37) It appears that, in the traditional contracts, BIM is still considered as a supplementary deliverable rather than being contractual itself. (37) This may lead to further arguments taking into consideration responsible parties (having in mind *professional liability* as well), limitations and liabilities in regard to BIM– thus, the timeline of the project may expand as well. Moreover, previously mentioned *ownership issues* can arise too if none of the *intellectual property* is mentioned in the contract. (15)

It is of a great significance to ensure the *data security*. Most of the times, BIM models are stored in both cloud and server storage. However, the stability and composure of such storages is very vulnerable, thus may be compromised – either through cyber-attacks or unintentionally wrong use. (37) This can result in the loss of important data, therefore, additional costs and expansion of the period of project.

Particular *licensing issues* related to BIM can happen in the construction projects too. To be precise, some of the designs used are not assembled by a designer that is licensed in the location of the specific project – it is probably because of the customized designs that meet the needs of the project. (7) Licensing issues might appear in such case due to related stakeholders (for instance, architects or engineers) sharing the BIM data with non-related sellers for the sake of special designs. (7)

Cost-Based Risks

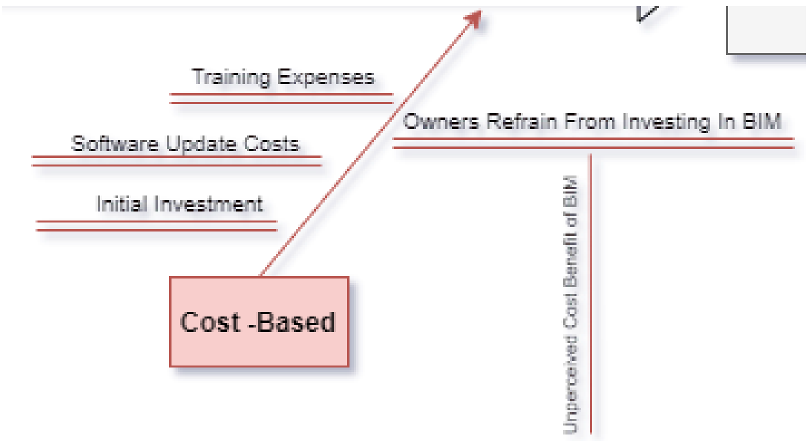

Figure 14 Cost-Based Risks of BIM (Author's Model)

Cost – Based risks are the ones related to the capital needed to “buy, do or make something”. (38) In this report, cost-based risks as *Training Expenses, Initial Investment, Unperceived Cost Benefits, Software Update Costs* and *Owners Refrain from Investing in BIM* were investigated (Figure 14).

In order to implement BIM in the company to make projects more efficient, it should be understood that it is a rather costly technology to invest in. Therefore, specific costs related to BIM cannot be avoided – *initial investment* costs and *training expenses* are the examples of those costs. It is necessary to mention that any construction project can reach its peak of productiveness only when obligatory set of BIM software is purchased by the company and it is used by the trained professionals. (34) This is why staff training is an essential part of implementation of BIM. However, it results in additional costs expected that covers not only the training itself, but the time and human resources assigned as well. (34) Once the first two steps are successfully achieved, undoubtedly, the constant update of BIM-related software is anticipated – thus, additional *software update expenses* should be faced throughout the management of various projects – it involves both costs of license of the current and software and the further purchases of newer versions. (39)

Nevertheless, there is another cost-related risk occurring– it is *owners refraining from investing in BIM*. This may happen because of *unperceived cost benefits of using BIM*. One of the reasons of this can be the lack of motivation from the owner's point of view considering investments in BIM. (34) As the owner is not directly linked to BIM, he may have a misconception about the importance of it – AEC possibly do not motivate owners enough as they "do not directly benefit from the use of BIM", especially having in mind the process of facilities management. (34) To give an instance, not having a cloud storage (which is a significant part of BIM), it takes longer for different stakeholders to access the information of the specific project and the recent changes are not available during the operation and maintenance phases. (34) Another study, which was done in 2016, states that no robust case of benefits of BIM for the universal economic was made – the opinion of BIM software platform still being illusive has been argued among AEC industry, thus, uncertainty towards investing in BIM is still existing. (15) Consequently, such a lack of determination can possibly lead to the same project delays and, likely, cost overruns due to that.

Management Risks

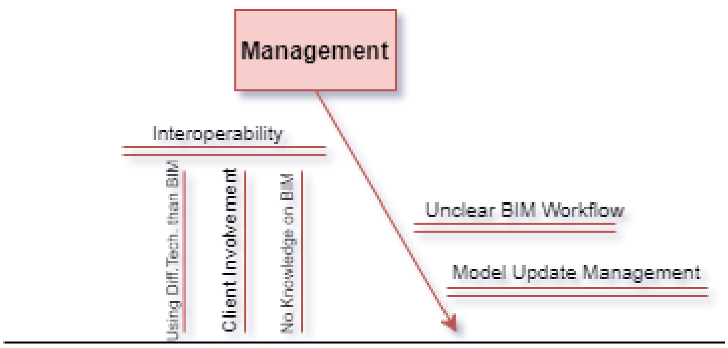

Figure 15 Management Risks of BIM (Author's Model)

Management risks are the ones related to "the control and organization of something" (in this case, BIM). (40) Such management risks as *Interoperability, Unclear BIM Framework* and *Model Update Management* were analysed (Figure 15).

Interoperability issues can happen when implementing BIM. *Interoperability* is defined as "the ability of equipment, systems, apps or products from different vendors to operate together in a coordinated way"- in other words, it can be explained as "interactivity" or "coordination". (41) In this report, risks related to different kinds of interoperability are going to be analysed. To begin with, the *lack of the client involvement* is one of the main issues when it comes to interoperability and BIM. Some of the studies mention the importance of client involvement in BIM – it leads to a well - working life cycle of every project (having in mind a building or any other piece of construction). (42) The reason of this happening can be because of the same misconception towards BIM – there may not be enough of information regarding BIM to individuals that are not directly related to the use of it (for instance, such end-users as clients). (34) As a result, the claim of the clients to use BIM is unsuccessful – thus, it may take longer to manage the project. (34) Another significant aspect of *interoperability* is having the same methods and processes while focusing on the same project. This should be ensured inside the company as well as through various sub-contractors connected to the project. (42) Sometimes, the risk may arise between different stakeholders when some of them are either not working with BIM (therefore, not being unaware of how to get an access to) or applying different methods while using it. (42) (34)

One more management-related risk of BIM is *Unclear BIM Framework.* It can be identified as a well-working application of BIM while different stakeholders exchange the data between each other. (34) When both roles and responsibilities are poorly defined, BIM workflow is not standardized and there are guidelines lacking, a risk of the staff working redundantly (having in mind unnecessary without being useful) may appear. (34) As a result, the coordination process can become complicated, therefore, can take more time than expected in order to operate. (34)

Constant updating of the BIM model is a must to make sure that the personnel have an access to the latest BIM data. (34) This is why poor *Model Update Management* can become risky. Particular risks of delays and errors can happen due to the fact that data entry is thought to be a manual process, thus making the update phase more vulnerable and time – dependent, especially taking into consideration data duplication or modification. (34)

4.3 Risk Analysis

Once the risk identification is done, it is necessary to investigate in how important each of those risks is. Thus, risk analysis is another step done in the risk assessment – it primarily consists of such detailed characteristics as "uncertainties, risk sources, consequences, likelihood, events, scenarios, controls and their effectiveness". (30) In other words, risk analysis is about assessing the probabilities of the risks identified before as well as the severeness of them – it gives a further support to be able to do risk evaluation and make decision-making on risk treatment (whether it should be treated or not, and how) as well as particular risk treatment strategies, and methods. (30) A good piece of data should be collected in order to do risk analysis successfully – data collection is a significant part of risk analysis.

Several studies have been analysed that have established various risks, including BIM-related ones, in the construction projects. Despite all these studies examining the risks and impact of them in the different countries (having in mind different levels of economy and development), similar repetitive trends have been noticed. The study regarding *"Design Changes in Construction Projects – Causes and Impact on the Cost"* examined the actions that were responsible for design changes in the construction projects as well as their impact on project budget. (43) At the very beginning of this report, the initial idea of design changes leading to not only the cost overrun, but also delays of the schedule and even productivity loss was mentioned– this demonstrates the aspects being strongly connected to each other. (43) Throughout the study, the cost overrun of 5 to 40 percent was found and thought to be a reasonable illustration of the particular circumstances. (43) Various causes of such overrun were studied, most of them – related to the particular groups of stakeholders. Having in mind the topic of this report, the ones connected to BIM risks identified before were chosen – it is believed to help with the further steps of risk assessment of the thesis (43):

- Lack of Technical Knowledge to Comprehend and Visualize the Project (Client - Related)
- Deficient Resources in Quality or Quantity (Designer - Related)
- Lack of Information Flow Among Parties (Designer - Related)
- Inadequate Training/ Inexperience, Lack of Knowledge in Building Laws, Codes, Constructability, Availability and Suitability of Materials, Engineering Design Techniques (Designer - Related)
- Lack of Design Standards (Designer - Related)
- Lack of Experience About New Construction Technologies (Contractor - Related)
- Insufficient Working Drawing Details (Contractor - Related)

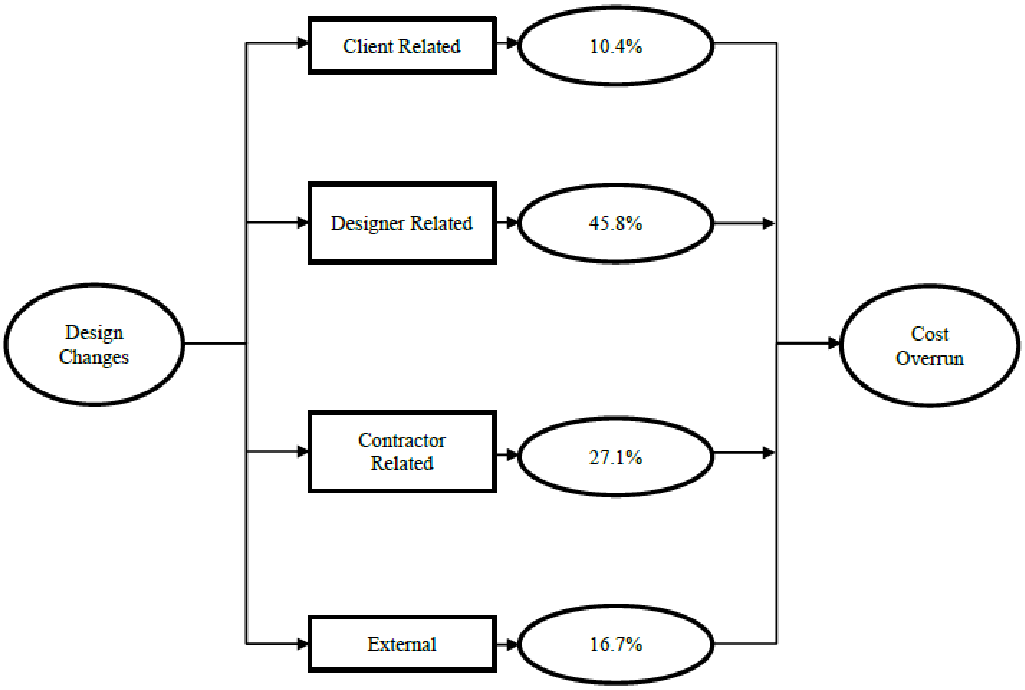

Figure 16 Impact on Cost in Construction (43)

Every stakeholder group with its causes declared in this study has an impact (in percentage) on design changes defined, which, as it was mentioned before, results in cost overrun as well as schedule delays and loss of the productivity (Figure 16). The percentage given in this study is expected to be used in the risk analysis as one of the aspects in the risk matrix chosen.

MGI has also investigated into the productivity considering construction industry. In the executive summary of the study *"Reinventing Construction: A Route to Higher Productivity"* the institute made a conclusion that there is a necessity for this industry to boost its productiveness in order to perform successfully since the demand for the new construction is rapidly rising. (44) Seven particular areas were found out to have vulnerabilities that stop this field from higher-productivity, three of which can be assumed to have connections with BIM – "*Collaboration and Contracting*", "*Design and Engineering*" and "*Technology*". (44) Each of the area has an impact on productivity as well as cost defined by the survey done by MGI (Figure 17). MGI mentions the significance of BIM – some of the BIM tools are thought to increase the productivity of construction projects by up to 50 percent. (44) Nevertheless, the survey done by MGI specified that underinvestment in IT and technology, and lack of training to use digital tools prevent from such a growth. (44)

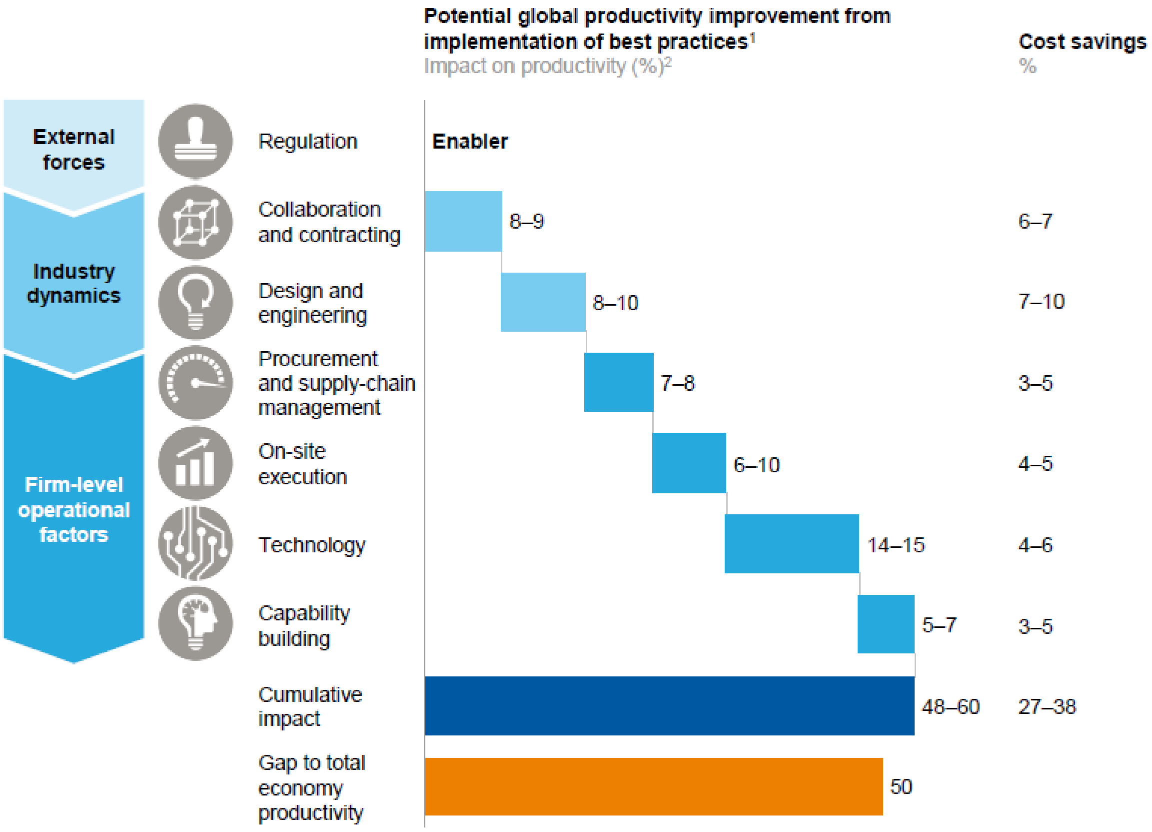

Figure 17 Seven Areas of Construction Industry Responsible for the Higher Productivity (44)

Another study *"Risks Leading to Cost Overrun in Building Construction from Consultant's Perspective"* is identifying the factors that may result in cost overruns in building construction projects using the Risk Map. This study is used as a fundamental example for the risks analysis done in this report whereas the information collected assists for the exact purpose of categorizing the previously identified risks of the BIM - a risk map was done taking into account the severity and frequency of risk factors. (45)

With a help of the questionnaire and data analysis, five groups of factors were identified in the study, among which factors similar to the ones defined earlier in this paper were found. For the identification of the scale of both frequency and severity, the index table from the same research was used (Figure 18). (45) Several calculated pieces of data from the study were imported to the analysis in order to ensure that the matrix is built properly with specific evidence involved - mainly because of the main factors analysed in the study being similar to the factors found in this report before. To give an instance, taking into consideration one of the cost-based risks – "*Initial Investment*" – can be compared to one of the factors examined in the study – "*Project Financing*". Therefore, the latter index of severity and frequency is used as an assumption in the risk analysis (75,96 % as a severity level, or H (high), and 68,27% as a frequency level, or H (high)). (45)

Index value (Scale)	Severity	Frequency
≤ 20%	very low (VL)	very low (VL)
20% - 40%	low (L)	low (L)
40% - 60%	moderate (M)	moderate (M)
60% - 80%	high (H)	high (H)
80% - 100%	very high (VH)	very high (VH)

Figure 18 Scale Used to Identify Factor's Severity and Frequency (45)

Once the index value of both of the aspects is calculated and defined, the risk map is done - that helps to determine every identified factor's risk zone. Every zone has a particular colour with the specific characteristics explained (Figure 19). For instance, if the examined factor had a high (H) level of the severity and very high (VH) level of frequency, it would belong to the red zone of the map, meaning the factor is critically important, therefore, urgent actions should be taken into consideration (Figure 20). (45)

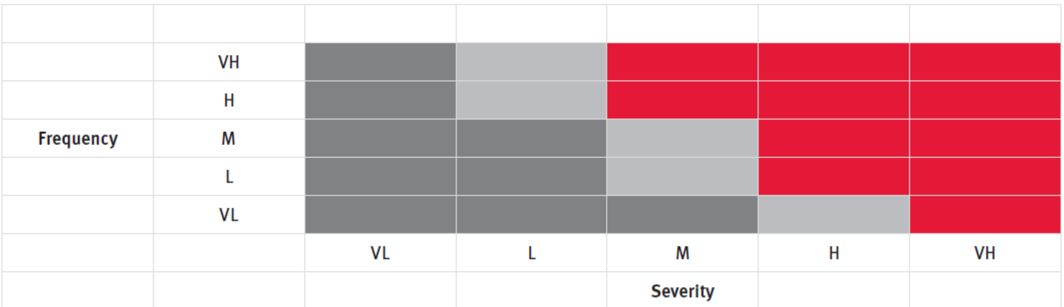

Figure 19 Zones of the Risk Map (45)

Severity Frequency	VL	L	M	H	VH
VL	green	green	green	yellow	red
L	green	green	yellow	red	red
M	green	green	yellow	red	red
H	green	yellow	red	red	red
VH	green	yellow	red	red	red

Figure 20 The Risk Map (45)

After the process of consolidating the information identified with the data from the various researches collected, the first step of risk analysis is done (Table 1). The table shows the majority of the BIM risks with their causes identified earlier in the report with the levels of severity and frequency stated. Two types of factors are referred to each of the cause – internal and external.

Internal factors are assumed to be mostly related to causes being impacted by the stakeholders such as clients, consultants, contractors and others whereas the rest of the causes are assigned to the "external" type of the causes – this was done based on one of the studies investigated before. (43) As it can be seen in the table, the majority of the causes have their severity and frequency stated. However, for the exact purpose of being as precise as possible, therefore, achieving an evidence - related analysis, additional data was collected ("Impact (Cost1)" and "Impact (Cost2)"). The first one ("Impact (Cost1)") is collected using the data from the MGI report, the second one ("Impact (Cost2)") – from the analysis done in the study regarding "*Design Changes in Construction Projects – Causes and Impact on the Cost"*. (44) (43)

RISKS	CAUSES	FACTORS	SEVERITY	FREQUENCY	IMPACT (COST1)	IMPACT (COST2)
TECHNOLOGY	Software Issues	INTERNAL	N/A	40	4-6%	45,15%
	Incompatible File Exchange Formats	INTERNAL	N/A	40		
LEGAL	Unclear Standards	INTERNAL/EXTERNAL	74,04	66,35	N/A	27,10%
	Ownership of BIM Models	INTERNAL	62,5	64,42		
	Professional Liability	INTERNAL	N/A	95		
	Contract Conditions	INTERNAL	78,85	67,31		
	Data Security	INTERNAL/EXTERNAL	N/A	70		
	Licensing Issues	INTERNAL/EXTERNAL	N/A	80		
COST-BASED	Training Expenses	INTERNAL	75,96	68,27	N/A	N/A
	Software Update Costs	INTERNAL	75,96	68,27		
	Initial Investment	INTERNAL/EXTERNAL	75,96	68,27		
	Owners Refrain From Investing In BIM	INTERNAL	75,96	68,27		
MANAGEMENT	Interoperability	INTERNAL/EXTERNAL	N/A	50	6-7%	10,45%
	Unclear BIM Workflow	INTERNAL	80,77	58,65		
	Model Update Management	INTERNAL	66,35	55,77		

Table 1 BIM Risk Analysis - First Iteration (Author's Model Based on (43) (44) (45))

After the identification of each of the index was completed, it was necessary to identify the scale - from very low (VL) to very high (VH), similar to the one explained in Figure 18. As a result, the second iteration of risk analysis is done (Table 2).

RISKS	CAUSES	FACTORS	SEVERITY	FREQUENCY	IMPACT (COST1)	IMPACT (COST2)
TECHNOLOGY	Software Issues	INTERNAL		M	VL	M
	Incompatible File Exchange Formats	INTERNAL		M		
LEGAL	Unclear Standards	INTERNAL/EXTERNAL	H	H		L
	Ownership of BIM Models	INTERNAL	H	H		
	Professional Liability	INTERNAL		VH		
	Contract Conditions	INTERNAL	H	H		
	Data Security	INTERNAL/EXTERNAL		H		
	Licensing Issues	INTERNAL/EXTERNAL		H		
COST-BASED	Training Expenses	INTERNAL	H	H		
	Software Update Costs	INTERNAL	H	H		
	Initial Investment	INTERNAL/EXTERNAL	H	H		
	Owners Refrain From Investing In BIM	INTERNAL	H	H		
MANAGEMENT	Interoperability	INTERNAL/EXTERNAL		M	VL	VL
	Unclear BIM Workflow	INTERNAL	VH	M		
	Model Update Management	INTERNAL	H	M		

Table 2 BIM Risk Analysis - Second Iteration (Author's Model Based on (43) (45) (44))

When it comes to the specific areas where not related data was found, it was assumed to integrate the information considering two researches into one data table – most of the times, the "severity" data missing was taken from both "Impact (Cost1)" and "Impact (Cost2)". This is believed to help achieve more accurate results. Finally, the heat map was done based on the risk matrix done before and the assumed criteria (Figure 21). The results defining the specific zone were calculated based on the formula/relation *"Risk = Consequence × Probability"*. (24)

IMPACT (SEVERITY)		LIKELIHOOD (FREQUENCY): None (Very Low)	Negligible (Low)	Marginal (Moderate)	Critical (High)	Catastrophic (Very High)
		1	2	3	4	5
Rare (Very Low)	1	1	2	3	4	5
Unlikely (Low)	2	2	4	6	8	10
Possible (Moderate)	3	3	6	9	12	15
Likely (High)	4	4	8	12	16	20
Very Likely (Very High)	5	5	10	15	20	25

1	5	No Action
6	10	Monitor
11	15	Action
16	20	Urgent Action
21	25	Stop

Figure 21 Heat Map Criteria (Author's model based on (45))

RISKS	CAUSES	FACTORS	SEVERITY	FREQUENCY	IMPACT (COST1)	IMPACT (COST2)	ZONE
TECHNOLOGY	Software Issues	INTERNAL	N/A	3	1	3	3
	Incompatible File Exchange Formats	INTERNAL	N/A	3			3
LEGAL	Unclear Standards	INTERNAL/EXTERNAL	4	4	N/A	2	16
	Ownership of BIM Models	INTERNAL	4	4			16
	Professional Liability	INTERNAL	N/A	5			10
	Contract Conditions	INTERNAL	4	4			16
	Data Security	INTERNAL/EXTERNAL	N/A	4			8
	Licensing Issues	INTERNAL/EXTERNAL	N/A	4			8
COST-BASED	Training Expenses	INTERNAL	4	4	N/A	N/A	16
	Software Update Costs	INTERNAL	4	4			16
	Initial Investment	INTERNAL/EXTERNAL	4	4			16
	Owners Refrain From Investing In BIM	INTERNAL	4	4			16
MANAGEMENT	Interoperability	INTERNAL/EXTERNAL	N/A	3	1	1	3
	Unclear BIM Workflow	INTERNAL	5	3			15
	Model Update Management	INTERNAL	4	3			12

Table 3 BIM Risk Analysis - Final (Author's Model Based on (43) (44) (45))

The Heat Map shown above (Table 3) summarizes the risk analysis as a part of risk assessment. To sum up the analysis that have been done so far, it was found that seven of the fifteen risks identified a combination of severity and frequency, therefore, are placed in the red zone (with the highest score of 16 out of 25) – meaning that most of the attention should be paid to them and urgent actions should be taken. The causes defined in this zone are coming from both Legal and Cost-Based risk categories. Moreover, two were located in the orange/yellow zone (from 11 to 15 points), three in the yellow/green zone (from 6 to 10 points) and three in the green zone (from 1 to 5 points).

4.4 Risk Evaluation

The purpose of the last chapter of risk assessment is to evaluate the impact of the results received previously in risk analysis – to do risk evaluation. In other words, the actual meaning of the risk to the people related or being impacted by, is defined. (46) Risk evaluation is needed in order to support the decisions along with the risks analysis done before, and compare the outcomes with the risk criteria or policies defined. (30) It also involves the establishment of the further actions – for instance, to do nothing, consider particular risk treatment options, take further analysis, maintain some existing controls, or reconsider the objectives defined before. (30) In other words, risk mitigation could also be done in this chapter – based on the results received, there is a need to suggest the possible, risk-reducing measures to improve the system.

In order to do so, the risk criteria/policy should be identified first. As the results shown in the analysis (Table 3), the risk category related to costs is the one with the highest risk score, therefore, the need to evaluate cost-based causes is thought to be prioritized. The criteria determined by the monetary value (additional costs in the budget) and time (delays) are going to be defined and compared. For the evaluation, particular cases connected to BIM and assumptions are going to be chosen for the further steps. The criteria of "minimization of the costs" is assumed.

First things first, BIM- related scenarios should be designed at the very beginning. For this, decision tree is going to be used. This graphical tool is going to help to provide a different view of the topic chosen – "a representation or model of the decision problem". (47) It is supposed to show all of the probable choices/paths which a decision maker or a stakeholder may take during the entire process with the probabilities, alternatives related to the decision taken as well as the consequences and the end results. (47) Most of the times, the decision tree is done from the left side, starting with the main decision, going towards the right side, that are followed by other decisions directly related to the main one. (47) Every of this decision has a few alternatives with their likelihood and outcome defined. (47) Therefore, first of all, a piece of statistics together with particular assumptions related to BIM are going to be made in order to design the decision tree.

Statistically, project delays do happen quite often in the construction projects – because of this, claim notices can be a result of it, meaning that the time overruns in the projects can be defined in the monetary value the same way the budgets are identified. (48) It is believed to prove the direct connection between the budget and schedule – the monetary consequences of the delays in the construction projects. (48) To give an instance, one of the studies declare that approximately 91 percent of all the construction projects face either smaller or bigger delays – some of the delays are thought to be not severe enough to even be considered. (48) The study also declares that most of the times, a time overrun from 10 to 30 percent is expected in the projects. (48) In some cases, 9,8 percent of the projects encountered a delay of 20% of the expected preliminary project time. (48)

In order to compare both delays and cost overruns, it is necessary to define both of these aspects in the same value – in the case of this report, previously mentioned monetary value is taken into consideration. In order to do so, a percentage of the cost that the delay may create should be find out. One of the surveys considering *"How much do delays actually cost construction projects?"* stated that, in general, an extra cost of 20 percent compared to the estimated budget is expected in the case of the project facing delays. (48) As an illustration of the survey analysed, 31,1 percent of the projects investigated had a 0-10% of the increase of the budget. (48) Another group of the projects (26,2 percent) declared a cost overrun of 11-20 percent in the construction projects. (48) The last group analysed - 3,3 percent - stated that the cost overrun in their project went up to 50 percent. (48) The study proved the impact of the delay on the project budget. Therefore, the importance of well-working BIM is assumed to be even more understandable. The numbers identified in this study are going to be used for the creation of the decision tree later in this chapter.

To be able to do the decision tree, a case should be considered. It is assumed that the company is discussing the need of BIM, therefore, has two main options – either to "invest" or "not invest" in BIM. Later, it is believed that the same construction company is planning on starting a project (with an assumed cost of 1 million (currency not mentioned)). Additionally, a probable case of not succeeding in getting a project is also stated. When investing in BIM, two more cases are assumed – "Efficient Use of BIM" and "Poor use of BIM". In the study *"Building Information Modelling (BIM): Trends, Benefits, Risks, and Challenges for the AEC Industry*", the data of 32 projects of the higher scale was collected and the reduction of 10 percent in the cost of the project was expected to happen when the use of BIM is considered as "efficient". (7) This is going to be assumed for the first case defined in the decision tree that is going to be done in this report. Afterwards, three levels of delay are going to be assumed – "High Delay", "Average Delay" and "No Delay". In the situation of getting no project, "No Delay" is supposed to be the case. The probabilities and percentage of delays are thought to be identified (Table 4) with the help of the study investigated before ("*How much do delays actually cost construction projects"* (48)). When it comes to the delays in the case of "Efficient Use of BIM", a decrease of 7 percent in the cost of delay is assumed – according to the study, one of the benefits of successfully implementing BIM in the construction project is the expected 7 percent reduction of the project time (7) – as no particular project time is defined in this decision tree, the reduction of the cost of delay is going to be presumed.

Type of Delay	Assumed Probability	Assumed Percentage of Budget
High Delay	9,8%	20%
Average Delay	90,2%	10%
No Delay	0%	0%

Table 4 Assumptions of Delays for the Decision Tree (Made by the Author Based on (48))

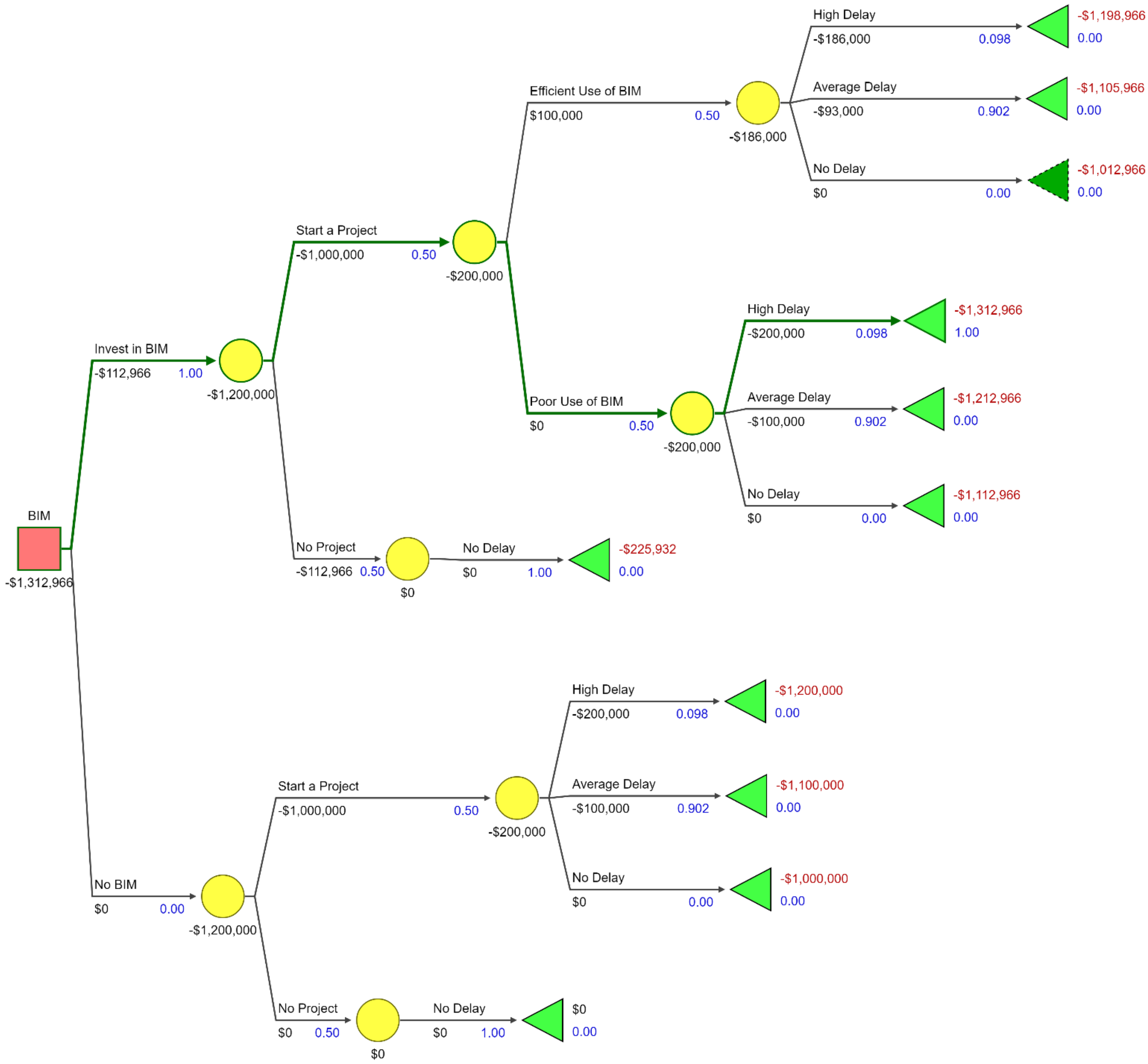

Figure 22 Decision Tree (Author's Model Based on (48) (7))

The figure above (Figure 22) shows the final decision tree. As it is shown in the tree, it consists of two main options – invest in BIM or having no BIM. Each of the option has two conditions – starting a construction project or having no project at all with the equal probabilities assumed (since it is believed to be equally likely, every probability is equal to 0,5 or 50%). In the case of starting a project with the investment in BIM involved, the success in implementing the technology is defined into "efficient" and "poor". The majority of the decisions have three levels of delay defined whereas the case of "no project" has a "no delay" option stated. According to the decision tree made, as the worst-case scenario (with the highest negative payoff of approximately 1,313 million), the option "Invest in BIM- Start a Project – Poor use of BIM" with the high level of delay is found out (as a "mini-min" rule) (Figure 23).

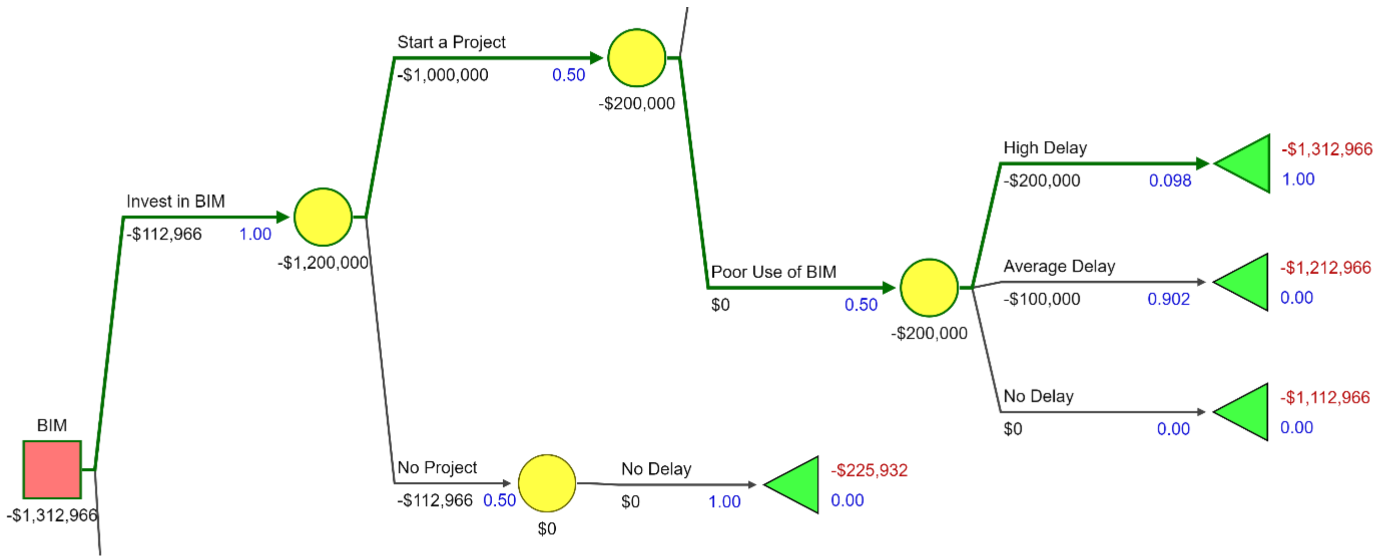

Figure 23 Decision Tree with the Worst Case (Author's Model Based on (48) (7))

The results show the importance of successful implementation and adaptation of BIM in the construction industry – the case of having no BIM and starting a project resulted in a lower negative payoff compared to the "Poor use of BIM" case. However, "Efficient Use of BIM" ended up as the one with the lowest negative payoff when the case of starting a project is chosen. Additionally, the case of neither investing in BIM nor starting a project is resulted with the payoff of 0, nevertheless, it should be understood that the profit is not defined in this decision tree, meaning that, in this case, no profit is believed to be achieved, which is not always a case – therefore, in the final result, it would not be considered as the best decision.

In order to have a more precise decision tree, the added expected value should be defined. In this case, the decision's consequences will involve only monetary gains or losses. That is why the expected value can be called the *expected monetary value* (EMV). It is calculated as (47):

$$EMV = Probability \times Impact$$

Equation 1 Expected Monetary Value (47)

In the case of this report, the impact is the payoff. It is believed that it is rational to choose the alternative with the highest EMV – if it is negative, the lowest one. (47) The expected value can be calculated as a weighted average of the possible outcomes. To give an instance, the EMV of the case "Invest in BIM- Start a Project- Efficient Use of BIM- High Delay" is:

$$EMV_1 = (-186000) \times 0{,}098 = -18228$$

This means that investing in BIM and working on construction projects while using this technology efficiently many times with the longer delay, it would create an average value of -18228.

Another example could be the case of "Invest in BIM- Start a Project- Efficient Use of BIM-Average Delay". This can be calculated as:

$$EMV_2 = (-93000) \times 0{,}902 = -83886$$

Having in mind that investing in BIM and working on construction projects while using this technology efficiently many times with an average delay, it would create an average value of -83886. This shows that choosing between these two decisions, on the average it could be better to choose option EMV_1. However, the decision may differ depending on various aspects and changes in the decision tree itself – as this is considered as a process of study work with particular assumptions done, the result can be different compared to the real case, where the data is thought to be more accurate. Moreover, such aspects as the impact of human errors, the price of these errors, definition of efficiency, time pressure, the complexity of the projects as well as various changes may also be investigated, however, as it was mentioned in the "Limitations", due to the period of this semester, this can be analysed in the future works regarding the case chosen.

4.4.1 Possible Risk Mitigation Strategies

After analysing and evaluating the risks of BIM, in this sub-chapter, it is necessary to do the risk mitigation in order to set which options could be applied to either eliminate or reduce the potential risks and the impact of them on both budget ant time line of construction projects, as well as increase the control over the same risks. The strategies may vary depending on every organization's values, objectives, risk criteria and other aspects considered. (30) The options chosen can be related to such aspects as "avoiding the risk by deciding not to start or continue with the activity that gives rise to the risk", "taking or increasing the risk in order to pursue an opportunity", "removing the risk source", "changing the likelihood", "changing the consequences", "sharing the risk", or "retaining the risk by informed decision". (30) In this report, risk mitigation strategies for each of the risk of BIM identified before are going to be stated with a help of the methodology use throughout the entire research. Later, a short risk assessment of the mitigation strategies is going to be done in order to define whether these measures are useful and efficient as well as the additional risks related to them.

The table below (Table 5) defines some of the measures recommended by various studies for each of the BIM risk category mentioned in this report.

RISK CATEGORY	RISK	MEASURES
Technology	Software Issues Incompatible File Exchange Formats	Common file format in BIM execution plan (5) Common data environment (5) Establishment of standard protocols or information delivery manuals (34) Interoperable BIM platform, plug-ins (34)
Legal	Unclear Standards Ownership of BIM Models Professional Liability Contract Conditions Data Security Licensing Issues	Everyone responsible for their own data input (5) Contractual framework (5) (New form of contract (15)) Network servers with monitored access (5) BIM execution plan (5) Risks and issues addressed in the contract (7) Cyber security policies, apps (34)
Cost Based	Training Expenses Software Update Costs Initial Investment Owners Refrain from Investing in BIM	Client is expected to accept the costs (5) BIM use promotion (7) Pre- planning of costs (34) Cost allocation (34)
Management	Interoperability Unclear BIM Workflow Model Update Management	BIM model maintained and updated by AEC (defined in BIM execution plan) (5) BIM Manager (15) or Coordinator to assign duties (34) Integrated design methodology combined with efficient engagement with stakeholders (15)

Table 5 Risk Mitigation Strategies (Author's Model Based on (5; 34) (15) (7))

Technology Risk Reducing Measures

As it was mentioned before, technology risk category is connected to those kinds of risks that are related to BIM software and its components (3D models, data related to it and others). According to the risk analysis, both of the causes identified in this category resulted in the green zone, with the highest point of 3 each, meaning that no action should be taken into consideration while attempting to either reduce or eliminate the risk. However, several studies have recommended some of the measures related to these risks. For instance, when it comes to the *Incompatible File Exchange Formats,* BIM execution plan is thought to be one of the solutions. It is defined as a “plan prepared by the suppliers to explain how the information modelling aspects of a project will be carried out”. (49) With a help of BIM execution plan, such things as common software, model deliverables, common file format and its sharing are thought to be discussed. (5) Stakeholders such as AEC, BIM manager and information manager should be the ones to participate in BIM execution plan meetings in order to keep developing the plan in accordance with the current needs of a particular project. (5)

Taking into consideration *software issues*, for example, having different versions of it, it is recommended to establish a standard protocol, a manual explaining the delivery of information or even fully digitalize the data used. (34) This way, it is believed to reduce the risk of losing the data. (34) Definition of the specific set of software used in the construction project can also be mentioned in the BIM execution plan if necessary.

Legal Risk Reducing Measures

Dealing with the legal risks of BIM in the construction projects, it is thought that most of them are connected to various BIM-related laws and regulations. This category has six causes identified, three of which reached 8-10 points, having in mind that some monitoring is needed. The rest of causes (three) resulted in the red zone, with the highest score of 16 – meaning that urgent actions should be taken into consideration. The riskiest causes were the ones related to “unclear standards”, “ownership of BIM models” and “contract conditions”. According to the studies analysed in this report, such legal risks are rather common in the construction projects, therefore, various risk mitigations strategies are being offered. To give an instance, in order to avoid “unclear standards” for BIM in the same construction projects, one of the research projects recommends creating a contractual framework as a part of a contract. (5) This way, the most common risks are expected to be described and involved in the framework and are known for the owners responsible for the project and its management – such a framework may later become a BIM standard itself. (5)

For the lack of the determination of the ownership of BIM-related data, one of the strategies could simple be to define the exact ownership rights as well as the responsibilities in the contract – because of this, risks of copyright issues may be avoided. (7) Other studies (5) offer that the ownership should still belong to AEC, however, this may depend on every specific project. Therefore, the first recommendation is thought to be more reliable when it comes to avoiding the risk of conflicts in the later phases of construction project. The ownership of data may still belong to AEC, but should be defined in the contract itself.

Considering contractual state and the conditions of contracts, some major improvements should be considered. First of all, it is suggested that BIM deliverables should be identified as contractual ones, not the supplementary. (37) Moreover, such BIM deliverables as virtual simulations, walkthroughs and others should be a part of contract – most of the times, these deliverables are missing due to the use of the traditional contracts, which usually define the data as 2D only. (37) BIM execution plan may be useful in order to reduce the contractual risks of BIM as well – the deliverables and their sharing can be discussed in this plan by both the client and AEC. (5) However, the strategy chosen also depends on the particular construction project and the best practice should be applied.

Cost – Based Risk Reducing Measures

Cost – based risks are directly related to both the budget and the expenses while implementing and adopting BIM. The strategies are going to be analysed for all the causes identified due to the fact that the entire category is covered in red zone, with the highest score of 16 points, having in mind that the urgent actions must be performed. When it comes to the risk mitigation of this category, the early phases of the project are believed to play the main role – well done preliminary cost plan with costs of BIM involved in it (the process of pre-planning of costs) is the one that should help to manage the costs related to BIM in the company. (34) Even though the plan itself cannot reduce the costs, however, it is expected to prepare the client with the particular budget established at the beginning of the project or prior to it and may be useful for the further decision-making processes as a part of assessment. (50) Nevertheless, extra costs for such estimates should be expected as well. In the case of receiving a preliminary cost plan that does not meet the end result of the project, for example, due to increasing prices of the materials (or software), wrong assumptions or changes in the design, unexpected additional costs may be faced. (51) It should also be assumed that the client is that stakeholder who is believed to face all the costs – except the additional costs, which are recommended to be covered by either the contractor or the consultant, depending on every specific occasion. (5)

Having in mind owners not willing to invest in BIM, the risk mitigation strategy can be connected to educating those groups of stakeholders first. This can be done individually or through various policies this industry can create. (7) The BIM itself is a great piece of technology whereas the right implementation and use of it may lead to a number of advantages, however, it is still challenging to promote for the majority of the construction industry. (7) It is believed to take some time for the technology to become the main lead in the previously mentioned industry, which could result in the reduced costs as well as time savings. (7) Therefore, despite the category and this particular cause identified as the risky one with urgent actions necessary, no rapid solutions for the risk reducing measures are yet to be found.

Management Risk Reducing Measures

According to "Risk Identification chapter", the risks of management are related to either controlling or taking care of the organizational aspects of implementing and adopting BIM. As it can be seen in the risk analysis, the category has three causes in total, two of which scored 12-15 points, meaning that some actions should be performed whereas the first cause has reached the score of 3 points, meaning no risk mitigation is needed. Therefore, the last two causes are going to be analysed with the particular risk reducing measures recommended.

To begin with, "Unclear BIM Workflow" is found to be one of the riskiest one when it comes to management aspects of BIM in construction projects. Some of the strategies thus should be considered. For instance, in order to avoid the coordination between different stakeholders becoming too complicated, it is suggested to hire a BIM manager that could be responsible for such activities as deciding the responsibilities, access of the model, software, security, data information and archiving as well as transmitting and others. (15) In order to avoid the risk of time overruns in the projects, another suggestion could to implement particular duties in the project prior to the start of it – it is believed to involve all the stakeholders participating in the BIM process throughout the entire project. (15) However, the accuracy of the duties defined in the project is very significant – any aspects missing may lead to conflicts – therefore, it is expected that the creation of such a contract may be in a need of extra time. (15)

Another to some extent less risky cause belonging to the category of management risks is "Model Update Management". One of the measures recommended is to ensure that AE should maintain and update the model and be responsible for the whole model management. (5) This can be done throughout BIM execution plan or mutual agreement. (5) It could also be beneficial to create an "integrated design methodology" together with related stakeholders, which could not only help to follow the update of the model throughout various phases of the project, but also assist in the creation of sustainability. (15) This could also be discussed within the BIM execution plan.

5. Conclusion and Discussion

To sum up, the report was made in order to do the risk assessment of Building Information Modelling in the construction projects, with a focus on an impact on both budget and time schedule of the project that BIM may have had affected. BIM is believed to have a variety of advantages when it comes to the use of it in the construction industry. However, the report indicates the risks of BIM while implementing and using this technology. The GFRM model was chosen as a foundation for this report, while paying attention to the assessment of the risks throughout the risk management. With a help of this model, such steps as Risk Identification, Risk Analysis and Risk Evaluation were identified and analysed. Moreover, some of the measures were recommended in order to either avoid or reduce the risks identified before, with a short assessment of them done as well. Throughout the making of this report, limitations regarding different levels of development of BIM in different countries and time restrictions of this semester were faced.

In the risk identification part, the main four categories of risks were defined – technology risks, legal risks, cost-based risks and management ones. In this chapter, the Cause-Effect analysis (Ishikawa/Fishbone) was also implemented to identify the risk types/categories and the exact causes that belong to each of them – this way, the connection between each other was visually shown and proved. It should be mentioned that the risks analysed in the risk identification chapter are the ones related to having an impact on the cost overruns and project delays mainly. Technology risks category was mostly related to BIM-related software, its versions and files as well as complexity and compatibility. These types of risks were thought to impact the time schedule and costs due to a variety of misunderstandings, loss of data and other similar difficulties expected. One more category identified in this report was legal risks. The category covered risks related with vulnerabilities of the standards, contracts and their conditions as well as security of the BIM data. Legal risks were found to result in additional costs and expanded project time if not taken into consideration. Another category defined in the report was cost-based risks and was mostly connected to various costs it takes to implement and adapt BIM in the construction projects as well as the will of owners to invest in such a technology. Noticeably, the risks investigated were believed to have an impact on the cost overruns. The last category analysed is management risks. The risks identified in this category were mostly linked to BIM framework, interactivity between different stakeholders and the way BIM data is managed. Consequently, it was found out that those risks may have resulted in additional time needed to cope with them, thus, extra costs as well.

Once the risk identification was done, meaning that the risks were identified and classified, it was essential to make some analysis in this report and evaluate them – this step is needed to investigate in the significance of each of the risks as well as identifying which risks are the ones that should mostly be paid attention to. The data from the studies linked to the risks identified were collected and the particular model was created. With the help of external resources (researches analysing costs of design changes, improvements in the implementation of technology in the construction industry and others) and such tools as Risk Matrix and Heat Map, the model was made (Table 3) that was meant to evaluate all the risks by particular aspects - severity, frequency, and impact. Different colours in the table explain the level of actions considered - whether there was an urgent need to respond to the risks, some or no action needed. According to the risk analysis, out of fifteen causes listed in total, seven of them were in the red zone – it means that these causes may have the highest impact on the budget and schedule in the construction projects, therefore, urgent actions should be discussed.

In the evaluation part of this report, an assumption was made in order to evaluate the impact and consequences of the results investigated before in the monetary value (financial magnitude). For this, a decision tree was used. The data collected considering projects delays and their impact on the budget proved the connection between these two aspects and helped in the development of the decision tree. With the help of the case assumed in the decision tree, according to the results achieved, the case of investing in BIM, starting the project while using BIM poorly and expecting a high level of delay was found out to be the worst one (with the highest negative payoff of approximately 1,313 million).

When it comes to the risk mitigation, beneficial risk reducing measures for each of the category of risks were expressed as the recommendation. With an assistance of various BIM- related studies, most of the causes of each of the category of risks got the most suitable risk mitigation strategies recommended. The necessity for the report to investigate in how the recommended measures could be implemented as well as affect the constructions projects was apparent – a short risk assessment of risk mitigation strategies was done. It was analysed that despite most of the measures being able to help to reduce or avoid the risks, some of them should be considered carefully in order not to encounter additional risks.

BIM has become a significant part towards digitalization process. With a help of this technology, the majority of the construction projects were transformed into virtual representations – such steps of the project as design creation, estimations, visualizations, various analysis and calculations were converted from hand drawings to three-dimensional kind of data. In the construction industry, BIM is believed to assist in improving quality control, data integration between the stakeholders, monitoring and assessment as well as estimations for time, costs and materials. As the scale of construction projects is rapidly growing, so is the need for BIM to be implemented and adopted in most of the related companies. However, as this is happening, a number of risks appearing that have an impact on project budget as well as timeline. Consequently, the report shows that not considering some of those risks may result in cost overruns and delays of the projects. The report also shows that the efficient and successful use of BIM is as important as implementation of it in general – investing in BIM and not adopting it successfully may lead to additional costs rather than gaining profit. Having said that, despite all the challenges and dilemmas BIM may be facing, it is believed to become an even more common thing among various parties in the construction industry worldwide, therefore, could eventually improve the effectiveness of such projects as well as reduce the costs. The case of this report is thought to be coming from rather of a wide topic, therefore, future investigations and analysis could be done to get into this particular topic deeper as well as create a better risk assessment of BIM. As this technology is believed to be used further, more risks related to it may appear. That is why, future research regarding BIM and the development of it may be necessary.

6. List of Figures

Study Board of Civil Engineering
Thomas Manns Vej 23 DK - 9220 Aalborg East
www.build.aau.dk

7. List of Tables

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9. Appendix

9.1 Cause – Effect Analysis of BIM

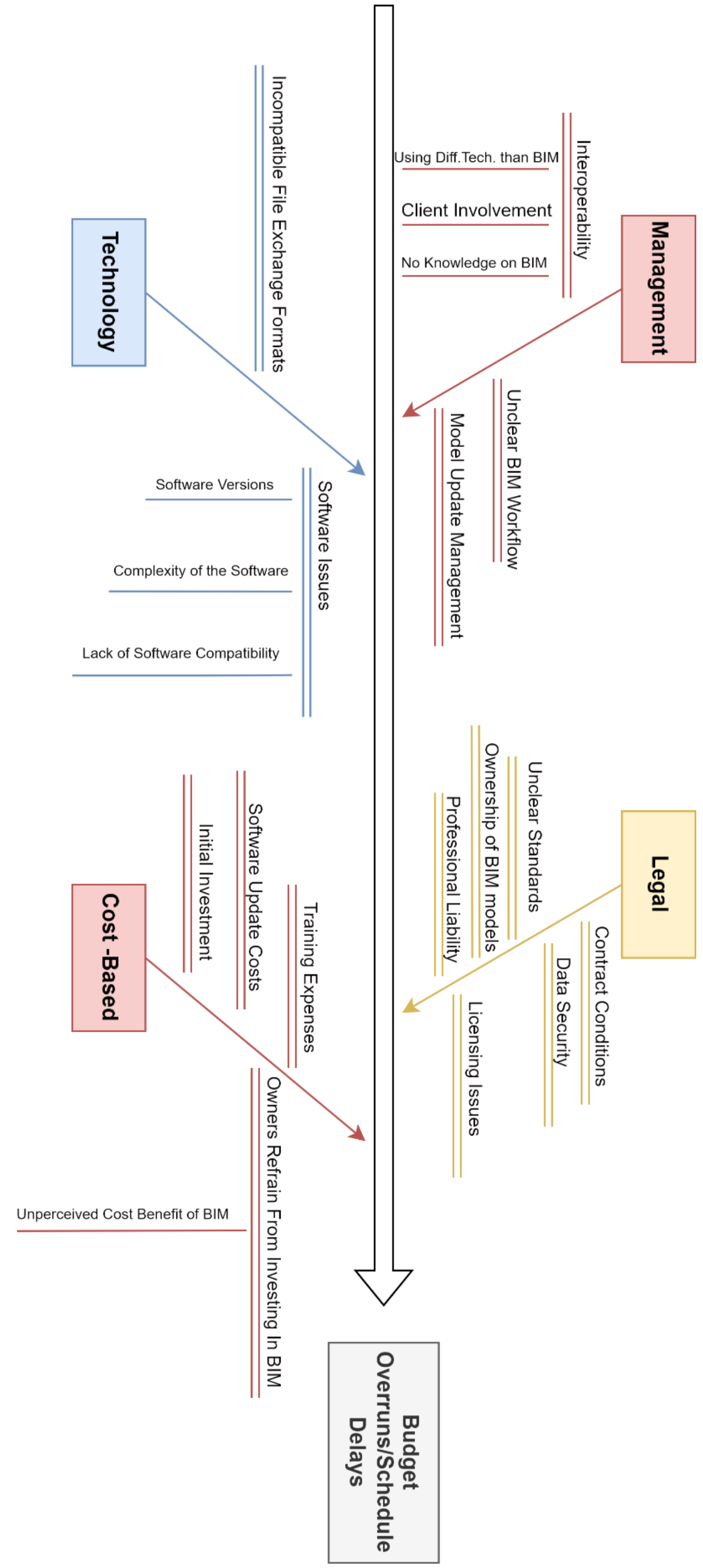

Figure 24 Cause – Effect Analysis of BIM (Author 's Model)

9.2 Decision Tree

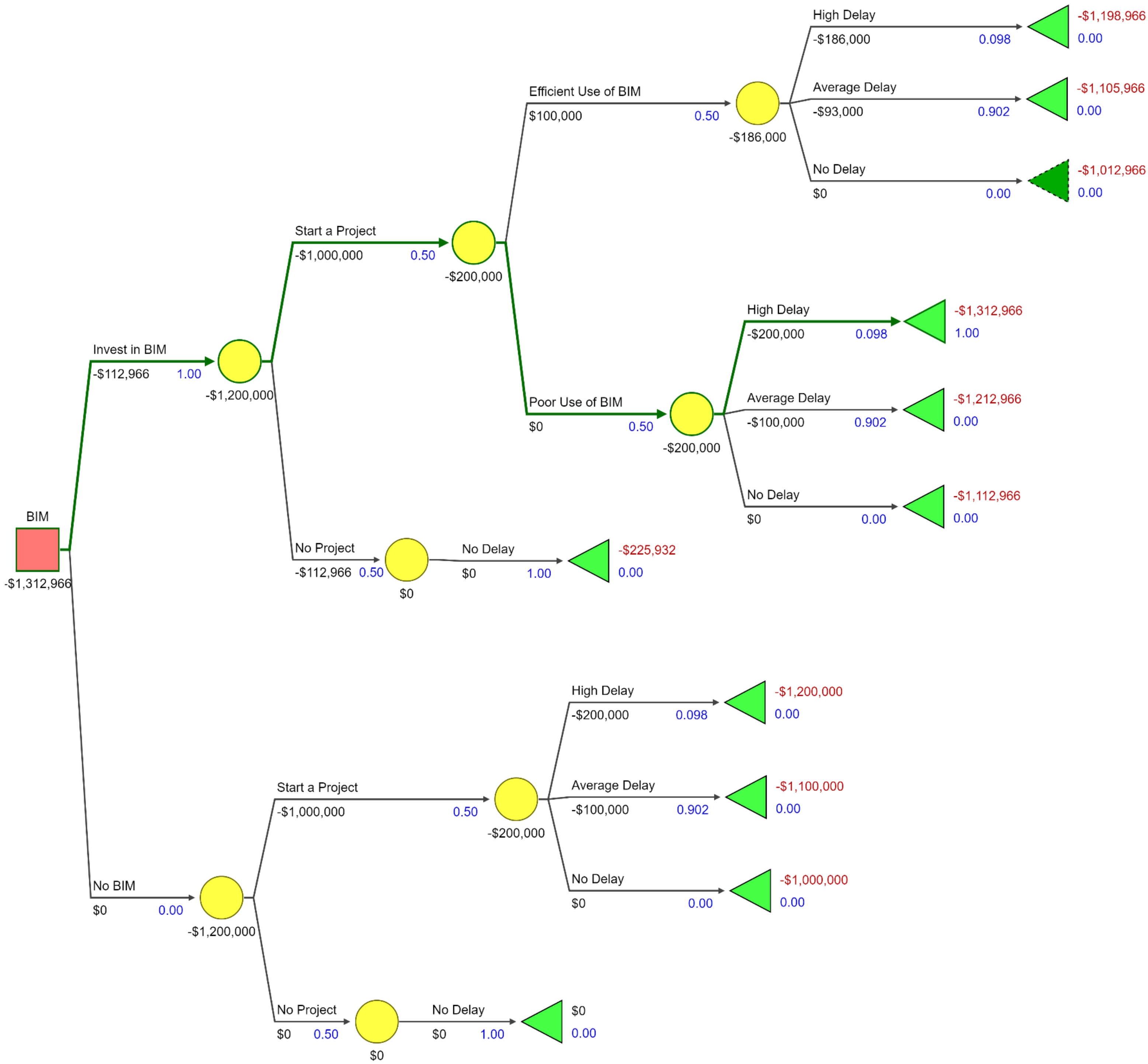

Figure 25 Decision Tree (Author's Model Based on (7) (48))

9.3 Uses of BIM

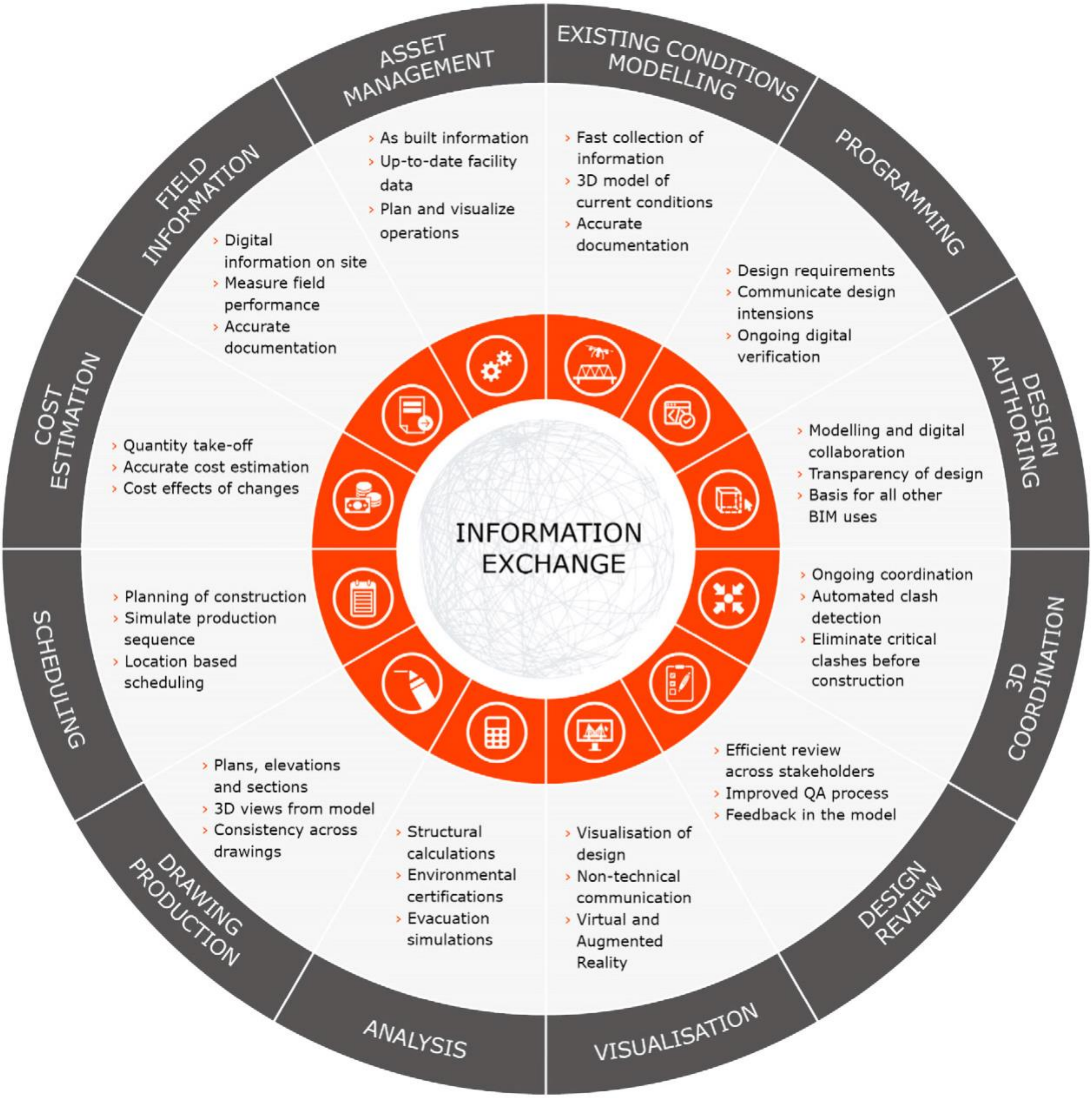

Figure 26 BIM Uses Identified by Consulting Engineers (13)