Cost and Benefit Analysis of BIM Implementation in Construction Projects

Marialena Koptsopoulou
MSc Construction Management & Engineering

bam international

TU Delft

(This page is intentionally left blank)

Cost and Benefit Analysis of BIM Implementation for Construction Projects

Master Thesis

by

Marialena Koptsopoulou

Master of Science in Construction Management and Engineering

Delft University of Technology

October, 2020

University	Delft University of Technology
Faculty	Civil Engineering and Geosciences (CiTG)
Master	Construction Management and Engineering
Author	
Name	Marialena Koptsopoulou
Student number	4907221
Committee	
Chairman	Prof. Dr. Ir. Hans L. M. Bakker, TU Delft
First Supervisor	Dr. Daan F. J. Schraven, TU Delft
Second Supervisor	Dr. Ir. Alexander Koutamanis, TU Delft
External Supervisor	Ir. Julián Odio Pozuelo, BAM International
TU Delft Delft University of Technology	Stevinweg 1, 2628 CN, Delft
bam international	H.J. Nederhorststraat 1, 2801 SC, Gouda

Source cover image: https://unsplash.com/@danist07

(This page is intentionally left blank)

PREFACE

This graduation thesis is in partial fulfilment of my Master studies in Construction Management and Engineering at TU Delft and was commissioned by BAM International. The Delft University of Technology along with BAM International provided me with valuable knowledge and important information in order to conduct an effective research on my desired topic; BIM Implementation.

This report includes the whole progress of my thesis project. It represents my journey which began last December and involved difficulties, ups and downs but irreplaceable personal development as well.

Personally, I would like to thank the members of my graduation committee, Prof. Dr. H. Bakker, Dr. D.F.J. Schraven and Dr.ir. A. Koutamanis, for the time they devoted in order to guide me efficiently. Firstly, the chairman of the committee, Hans Bakker for his helpful and specific comments which made me be more careful and critical. Firstly, my first supervisor, Daan Schraven, for the creative ideas he gave me in order to navigate me and enhance the quality of my research. Finally, I would like to thank my second supervisor, Alexander Koutamanis, for being always willing to hear and discuss my ideas and concerns as well as for the motivation he gave me to question myself and reach productive outcomes.

In addition, I would like to thank my supervisor in BAM International, Ir. J. Odio Pozuelo, firstly for giving me the opportunity to work together and for providing me with efficient guidance and life lessons from the first until the very last moment. Also, I feel grateful for all the people in BAM International who devoted their time to help me and provide me with a thorough insight of BIM implementation in AEC industry. Finally, I would like to express my gratefulness for my "family" in Delft for being there for me in good and bad times and my people in Greece for always encouraging me to realise my dreams and look forward to better days.

The journey of my research involved several difficulties. Apart from the crisis caused by coronavirus and the setbacks this situation brought, some undesired events happened in my personal life as well. However, these circumstances made me realise more than even that hard times cannot make me lose my optimistic mentality. Hence, I felt strongly motivated work hard in order to reach my goals and attain valuable results for TU Delft and BAM International.

Enjoy reading!

Marialena Koptsopoulou,

October 2020

(This page is intentionally left blank)

Executive Summary

Introduction and Research Approach

Building Information Modelling (BIM) constitutes an innovative way of creating and managing data among multiple disciplines and it was recently introduced in Architecture Engineering and Construction (AEC) industry. Considering the lack of relevant information and sufficient knowledge regarding these methodologies, their adoption is not encouraged. Although many studies have been carried out in order to present the benefits and outcomes of BIM, there is still lack of knowledge regarding its monetary value and the way it can be embedded in a company. In addition, researchers have not yet been able to substantiate all of the benefits because their intangible nature makes their quantification challenging.

The present research aims to substantiate the costs and benefits that are associated with BIM implementation. Their quantification will be attained specifically for the Execution phase of a project when, according to literature, costs are considered to be the highest. This quantification will constitute the foundations of an evaluative method and thus, the research is based on the following question:

Main: *What could constitute a standard method of evaluating the costs and benefits of BIM in Construction Projects?*

Firstly, the approach involves a thorough review of the published literature in order to acquire relevant knowledge on the costs and benefits of BIM applications as well as the existing methodologies to evaluate them. Following, the researcher executes multiple rounds of discussion with people working in the construction industry. These discussions provide her with a good understanding of the conditions of BIM Implementation during the project execution. Hence, when the first round is completed, the researcher already possesses a sufficient insight of the costs and benefits associated with BIM in each project. Therefore, she is ready to structure the evaluative method aiming to make it applicable in any construction project.

This Framework constitutes the core of the research and is created on an Excel spreadsheet. It provides guidelines which gradually lead to the quantification of costs and benefits and the calculation of the B/C ratio. The most important characteristic that the researcher strives for is a clear definition of the variables so the reader will be able to understand what lies behind the calculations. The list of the costs and benefits is formed according to the literature research and the experience of the experts. When the method is structured, the researcher applies it in 5 construction projects of the contracting company, BAM International, in order to test its applicability and analyse the results it generates.

Results, Validation and Conclusions

The result that is produced by the framework is the B/C ratio. This factor indicates the amount of money gained by the contractor for every unit of money invested on BIM implementation by him. The researcher makes an effort to interpret the factor calculated in each Case Study and ranges from 1 to 8. This interpretation is accomplished according to the knowledge she possesses and the feedback she received by the interviewees. The purpose of this interpretation was not only to explain what this factor stands for but also to test whether or not it corresponds to reality. In addition, in the cases where the factor was lower than expected, points of improvement were noted. In contrast, in the Cases where the factor was remarkably high, the reasons that led to this are also clarified.

When the interpretation is completed, an analysis of the costs follows. This analysis compares the 3 kinds of costs that were calculated in each case and analyses the reasons that caused the Cost of Personnel being significantly higher than the rest. The same analysis follows for the benefits and the workflow that produced the highest benefit in each case. In the majority of the Cases, the most beneficial workflow is the 3D Model while the 4D Planning seems to be promising and for future projects. The purpose of these comparisons is to define and understand the sources that produced each positive or negative cost and take advantage of them in future projects, considering that the goal of the contractor is to enhance its performance and achieve higher benefits.

The synthesis of the results intends to indicate how these results can be used and the impact that they could have on the BIM strategies of contracting companies. The most attention is given on the Cost of Personnel which constitutes the highest and most sensitive type of costs. In this part, the researcher tries to come up with some methods based on the findings of the research in order to enhance the BIM strategies. For example, the establishment of BIM Standards seems a possible way to reduce the long working hours while the focus on the critical activities would bring higher monetary benefit.

Following the chapter of results, the validation of the Framework is presented. This validation consists of two parts; the quantitative part which involves an application of the method in a pilot project and the qualitative part which involves the opinion of experts about the proposed method. Both parts provide useful comments and points for improvement. On the one hand, the application in a pilot clearly shows the functionality of the Framework in a project which is still in progress. On the other hand, the discussion with experts that had not been involved before, confirms the soundness of the Framework and the extent to which it could be standardised. Moreover, these people suggest valuable corrections based on their knowledge and expertise.

The final part of the research, the conclusions, aims to answer all the research questions that have been formed at the beginning of the research. In this way, the researcher reaches gradually the answer to the main question that motivated the whole study. This Framework which constitutes a transparent method of evaluating BIM Implementation in projects produces valuable findings regarding the highest type of cost and the most profitable BIM workflow. These results when they are interpreted by the contractor, they can help him upgrade his BIM strategies and improve his performance in order to offer competitive products to the clients. Also, if the contractor integrates the points that are analysed in the synthesis of the results, he can possibly attain higher benefits and lower costs in future projects. Finally, if this method constitutes a standard procedure and is adopted by the contractor at the beginning of each project, it can help him monitor the progress of BIM Implementation; the costs that are required and the benefits that are generated.

Recommendations

The last part of the research involves some recommendations made both for future research and for BAM International. With regards to the scientific field, the researcher suggests an investigation of more Case Studies in order to examine more benefits and possibly expand the list. Moreover, more costs that have to do with organisational and human issues could also be explored. In addition, an investigation of similar projects that were executed with 2D methodologies would also be useful. This investigation would allow the researcher make comparisons between traditional methodologies and BIM applications. Regarding BAM International, an extensive investigation of projects of similar characteristics with the ones investigated would be suggested. This would allow for more accurate comparisons among projects based on their B/C ratio. Finally, the researcher recommends to establish some BIM standards including the proposed method in order to record more data and eventually achieve quantification of intangible benefits. Moreover, based on the high values of the Cost of Personnel she suggests that future research should focus on how these long working hours can be measured and potentially decreased. All the above would eventually enhance the BIM Implementation in AEC industry.

TABLE OF CONTENTS

List of Tables

List of Figures

(This page is intentionally left blank)

1. INTRODUCTION

1.1 Research Background

Nowadays, Building Information Modelling (BIM) constitutes an innovative way of creating and managing information which prevails in Architecture, Engineering and Construction (AEC) industry. Therefore, more and more construction companies integrate this methodology in their operational context. At the same time, numerous efforts have been made in order to substantiate the actual costs of BIM and Digital Construction (DC) in construction projects. BIM can be considered as a development of Computer-Aided Design (CAD). Hence, execution of BIM technology will bring advanced capabilities in the AEC industry thanks to the improved collaboration among the stakeholders of the construction project, a smaller quantity of clashes and less rework. The wide research and evolution that has been implemented both in industry and academia level, have generated numerous effective BIM tools for the design, analysis and execution phase of a project (Migilinskas, Popov, Juocevicius, & Ustinovichius, 2013, p. 767)

In general, next to the research, the efforts that have been made recently in order to support BIM methodologies have been accepted by users. Financial methodologies such as the Cost and Benefit Analysis (CBA) and the Return on Investment (ROI) of BIM are proved to be helpful and motivating for adoption (Lopez, Chong, Wang, & Graham, 2016, p. 1). The advantages and barriers of BIM implementation in different kinds of projects have been recorded. Benefits are mostly realised during the design, construction, and operational phases of the lifecycle of an asset. Nevertheless, in most of the cases it is hard to quantitatively measure the benefits for each stakeholder or to make comparisons among different projects regarding their performance (Nepal, Jupp, & Aibinu, 2014, p. 5)

The vision of this innovative philosophy, BIM, is to construct a building digitally before actually building it. This gives the participants of a project the possibility to design, analyse, arrange, and inspect the project through a virtual world where it is less costly to make modifications than it would be on the construction site during execution where modifications are exponentially expensive (Hardin & McCool, BIM and Construction Management; Proven Tools, Methods, and Workflows, 2015, p. 2).

1.2 Problem Statement

It has already been recognised that BIM enhances performance and contributes in time and cost savings (Azhar, 2011). However, there is not sufficient available data to support this view (Neelamkavil & Ahamed, 2012). This lack of information in combination with the fact that the initial cost of BIM is perceived high and it only decreases cost later during the execution of the projects (Giel & Issa, 2013), are the reason why many people working in the construction industry claim that the costs outweigh the usefulness of this tool (Aranda-Mena, 2009). As mentioned above, BIM is one of the emerging technological means of working in the construction industry (Wu, et al., 2019). According to Li et al., due to the lack of sufficient information regarding the impact that can be actually achieved by BIM in real projects, construction stakeholders are not encouraged to take the risk and widely adopt BIM (Li, et al., 2014, p. 1). As a result, the adoption rate of BIM methodologies is lower than expected (Walaseka & Barszcz, 2017, p. 1234).

In addition, the recent users of BIM, and particularly the contractors, are hesitant because of the possibility of having a negative effect on their profitability due to the required investment in software and hardware and the learning curve that goes with it (Hergunsel, 2011). Generally, the challenges in measuring the positive and negatives lead to a high unpredictability about the expected outcomes of BIM investment from the side of asset owners and consequently, constitute a serious barrier to its adoption (Love, Simpson, Hill, & Standing, 2013, p. 214). Moreover, considering the recent introduction of BIM technology, there is still significant unconsciousness of its benefits.

It should be remarked, the opportunities that the concept of BIM offers vary. Firstly, BIM methodologies can generate an environmental impact. A recent concept in the construction sector involves the deconstruction and the reuse of structural elements which is part of the circular economy and aims to attain zero carbon. In order to implement this concept, there is high need of data. The reuse of elements is not a standard procedure. Instead, there is need of data that can be traced after a long period of time in order to implement reuse. This data should be linked with the structure during the design phase. The sixth dimension of BIM can therefore contribute. Particularly, 6D is the dimension of BIM which deals with environmental data relevant to sustainability issues. The BIM methodologies assist the project participants evaluate the environmental impact of decisions taken throughout all the phases of the project until its End-Of-Life. Thus, engineers can propose the most environmentally-friendly solutions regarding the construction (Bertin, 2019). In fact, the information mainly refers to the properties and the behavior of the element, the behavior of the whole structure and data regarding the procedure or reuse.

However, even if opportunities are clarified and sought, there is still unconsciousness of the outcomes. Although plenty of research findings have investigated issues such as the way BIM methods can be applied in order to simplify architecture, engineering and construction practices, there is still a lack of established quantitative robustness in understanding the way BIM technologies can enhance the general result of a construction project. The most remarkable challenges in BIM execution and approval within the AEC industry are appreciation and support by owners. Moreover, a well-structured and stable framework regarding the implementation of these practices which involves both financial and managerial results would reinforce the recognition of BIM within the industry (Li, et al., 2014). Although numerous case studies have focused on the benefits of BIM, they fail to quantify intangible benefits because their substantiation requires subjective assumptions (Barlish & Sullivan, 2012, p. 158). The most significant challenge in these studies is that the costs and benefits of BIM are hard to disentangle and even harder to be quantified (Lu, Fung, Peng, Liang, & Rowlinson, 2014, p. 318).

Tools able to measure the performance of a technology such as ROI have been already employed to explain the investment in BIM. Nevertheless, this measure does not precisely consider the actual costs and benefits that can be related to BIM methodologies. The weakness of these tools is that they rely mostly on anecdotal testimonies and subjective judgments of users. As a result, these self-reporting models overemphasise or undervalue the benefits and produced by BIM implementation. Therefore, the various views and perspectives on the profits of BIM lead to an overall misunderstanding of its expected results (Lu, Fung, Peng, Liang, & Rowlinson, 2014, p. 318).

The majority of the clients considers the process of the evaluation of a project as a financial obstacle that has to be faced and not as a procedure aiming to evaluate actual worth of technology. If conventional financial methods are employed in order to justify the adoption of the technology, then the evaluative process only aids management issues and sometimes is even limited only to financial management. Therefore, an approach which would evaluate BIM methods and aims to go beyond the conventional limits of financial evaluation is required (Love, Simpson, Hill, & Standing, 2013).

Even though, evaluative procedures and performance measurements are useful tools for people working in the AEC industry, there is still a lack of a standard methodology and criteria able to evaluate the BIM execution in a project. In addition, the measures and methods used in order to assess tangible benefits are considered to be difficult to implement (Jupp, 2013).

Until BIM practices are established as a standard within the AEC industry, the establishment of measures relevant to performance will continue possess an important role in the whole procedure of adoption of BIM methodology (Nepal, Jupp, & Aibinu, 2014, p. 7).

1.3 Research Objective

According to Nepal, Jupp and Aibinu, close to the growing levels of adoption of BIM practices, there has been an increasing interest in the evolution of BIM evaluation techniques, assessment tools and performance measures at both project and organisational level (Nepal, Jupp, & Aibinu, 2014, p. 1). In accordance with the Fig. 1, the objective of this research is to create a standard method that would evaluate the profits of BIM on project level. This method would quantify the benefits of BIM in comparison with traditional non-BIM technologies such as the 2D conventional methods. Following, the sub-objective is to apply the proposed Framework on actual construction projects and specifically on their execution phase and then, validate the proposed procedure. These parts would firstly indicate the way the method is applied and the results that are generate. Moreover, the analysis of the results would show what is the impact of this method on the BIM strategies of the contractors. Eventually, the validation will verify the usage of the procedure and would ensure the robustness of its functionality.

The most important barrier in the substantiation of the profits of BIM implementation, is the nature of the benefits. To be more precise, there are plenty of benefits that are not recorded on the spot when they happen on the construction site. As a result, when the project is over, there is not sufficient data in order to quantify them. Hence, they are considered as abstract and not quantifiable. The aim of this study is to suggest a procedure which would constitute a bridge between the tangible and intangible benefits, aiming to make them all as quantifiable as possible. This procedure would involve the detailed record of all the important information in order to assign monetary value to the costs and benefits of BIM.

Particularly, this procedure will acquire the form of a Framework would clearly define the variables taken into consideration (e.g. people, technology, process) and would constitute a useful guideline. Also, it would explore multiple aspects of BIM such as the improved collaboration, the prevention of errors and information management and would substantiate their costs and benefits. Furthermore, the sub-objective of the study would be to clarify how BIM applications can be beneficial for a specific part of the project; the Execution Phase. This part of the building process is chosen because is the most expensive and troublesome among the different phases. Particularly, the Execution takes place in different regions and the deployment circumstances of BIM are more demanding than they would be at the head office. In contrast, the Tender phase is only executed in the head offices of a company which is a more controlled environment. Therefore, the suggested procedure will be applied on the execution phase of the projects; namely, the Case Studies. Finally, the second part of the sub-objective is the validation of the proposed Framework. This validation will be twofold.

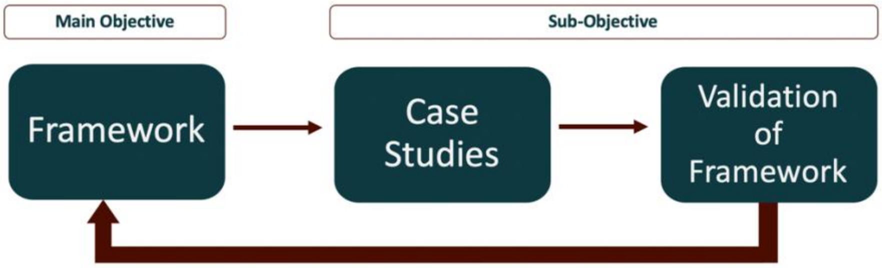

Figure 1 Objective and Sub-objective of the research

1.4 Research Questions

Research Questions are an important and useful part of the research. In fact, when they are formulated correctly, they can lead gradually to the goal of the study. The answers to these questions will help yield the necessary information to attain the final result; the development of a framework able to substantiate the Costs and Benefits associated to BIM implementation in construction projects. Considering that the objective of this research is to create a standard method of evaluating the costs and benefits, the main research question that will lead to this development is the following.

Main: *What could constitute a standard method of evaluating the costs and benefits of BIM in Construction Projects?*

In order to find the answer to the Main Research Question, the researcher should formulate a few corroborative sub-questions. These will help him acquire the necessary knowledge regarding the available evaluation tools, the needs that this framework will satisfy and the form that it will acquire. The Research Sub-questions are either exploratory or refer to the methodology, the results or the implications of the study.

Sub-question 1: *Which are the costs and benefits associated to BIM implementation?*

Sub-question 2: *Which unique characteristics of BIM (in comparison to traditional 2D methods) warrant an evaluation into its added value?*

Sub-question 3: *How can the costs and benefits associated to the implementation of BIM be effectively substantiated?*

Sub-question 4*: Which information is required in order to assign monetary value to the tangible benefits of BIM?*

Sub-question 5: *In which way do the costs & benefits of BIM implementation inform on the impact of BIM strategies of the Contractor?*

Sub-question 6: *To what extent can an evaluation of BIM into construction projects be standardised?*

1.5 Research Design

The research strategy includes an extensive review of the literature and conducting of interviews with people working in the construction industry. These people are Project Managers, Engineering Managers and BIM Engineers and provide the researcher with sufficient knowledge regarding the actual costs and profits associated to BIM. The aim of these interviews is to generate the essential data in order to form a quantitative and qualitative analysis of the benefits.

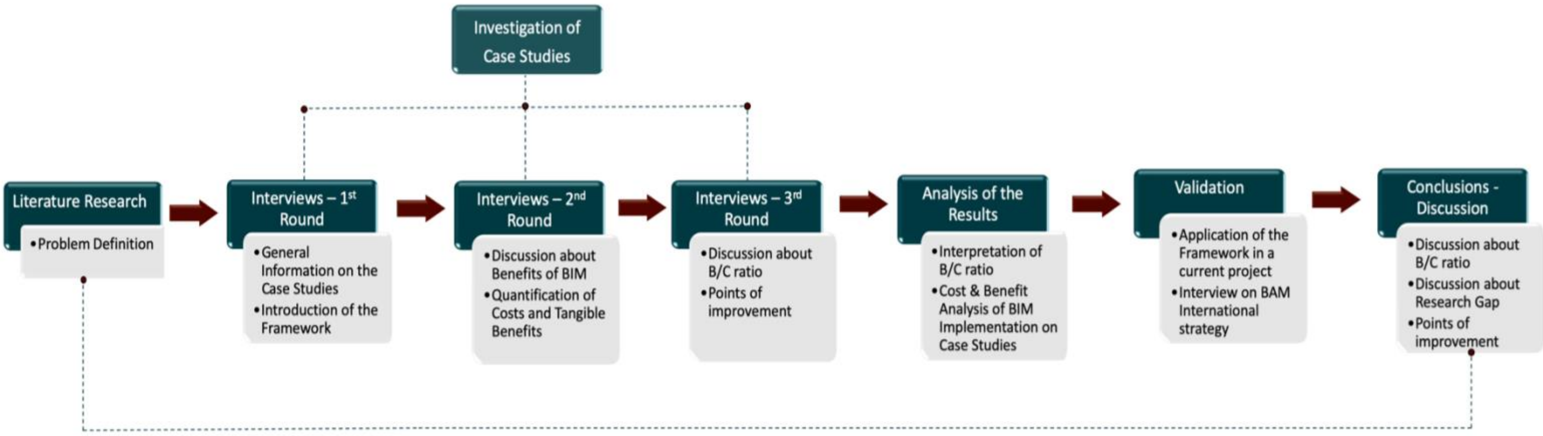

Figure 2 Research Design

1.5.1 Exploratory Research: Literature Study

Firstly, an extensive review of the published literature will be made. The literature will concern the use of BIM in the AEC industry. Moreover, the available tools and frameworks regarding the evaluation of BIM will be examined. Thus, the problem stated above and its causes will be explored thoroughly. In this way, the gaps regarding the substantiation of benefits will be detected and the researcher will know where to focus. Therefore, the present research will use the information that is already available and will focus on the presentation of novel ideas and of an efficient framework.

However, the main goal of this exploratory research is to dive into the costs and benefits of BIM implementation in the construction projects. This will help frame the baseline for the research that has to be done. Particularly, the researcher will have sufficient knowledge regarding the positive and negative costs associated to BIM usage. Hence, the researcher will acquire the knowledge that is needed in order to form the right questions for the interviews that will be conducted in a later stage. Thus, the literature study in combination with the interviews will allow her structure the proposed Framework.

Moreover, according to the published literature, two SWOT Analyses are also implemented. The one involves the traditional methods of creating and managing information, mainly the 2D techniques, while the second refers to BIM methods. These SWOTs will constitute the foundation for the evaluation of BIM implementation as they will clarify to the audience the advantages and disadvantages of each technique. In addition, the threats of BIM methodology constitute the motivation for the present research as the proposed procedure aims to encounter these threats.

1.5.2 Definition of Inputs and Outputs

This stage is of high importance and difficulty as well. As mentioned before, the problem regarding the evaluation of benefits is the lack of a transparent method which shows what lies behind the calculations. In fact, the barrier in the evaluation of benefits is the difficulty in quantification of them. Although the tangible benefits are quantifiable and can be associated a monetary value, the intangible are abstract and hard to substantiate. Therefore, the definition of the inputs (costs) and outputs (benefits) to be used in the CBA constitutes a challenging procedure. The researcher, based on the literature study and the experience of the interviewees will have to clearly define the variables to be taken into account. The next step will be to suggest a specific way to quantify them and generate numbers at the end of it.

1.5.3 Development of Framework

The next stage following the definition of the variables will be the development of the standard procedure. This procedure will acquire the form of the framework. In order to be applicable in any construction project by any user, it should consist of clearly defined steps. These steps would work as a guideline that will lead gradually to an accurate evaluation of BIM implementation through the quantification of Costs and Benefits. The aim of this Framework is to fill the gaps that the existing measurement tools have. This gap mainly involves the lack of a standard and uniform application. This lack does not help understand what lies behind quantification.

1.5.4 Data Collection

In order to apply the framework developed in the previous stage, the necessary data has to be collected. This data refers to the specific conditions of the construction project, the costs that were required in order to implement BIM and the benefits that were generated because of BIM application. Thus, this information can be provided only by people that have actually worked on the construction sites of these projects. Consequently, interviews with the people aforementioned will be conducted. During these interviews the researcher should be ready to ask specific questions that will lead her to acquire the data she needs.

Undoubtedly, several rounds of interaction are needed. On the first round, which has the form of an interview, the Project Manager would provide the researcher with some general information regarding the working conditions, the size, the value and the contract of the specific project. In addition, the BIM Engineer would be asked to give information regarding the BIM requirements from the side of the client along with the procedure that was followed regarding BIM implementation. On the other hand, the researcher would introduce the interviewees on the topic of the research and the data that is needed from them. Also, there would be given a thorough introduction and explanation of the framework; the way it works and the data that needs to be quantified. Consequently, on the following rounds of interaction, the experts would be ready to give to the researcher the information she needs in order to quantify the costs and benefits of BIM applications in each project individually. This information relies mostly on official reports of the company that record in detail the costs that were needed and the benefits that were acquired. The reports of the benefits involve Requests or Information (RFIs), Risk Registers, Clash Detections, Time Planning, etc. Finally, when the quantification procedure is completed and the B/C ratio is estimated, a third round of interviews would follow. However, this round acquires rather the form of a discussion as the results are discussed and Project Managers and BIM Engineers are asked to make comments on it.

1.5.5 Case Studies – Projects

As already mentioned, the framework suggested will be potentially applicable in any construction project. The most suitable approach would be a Model Developing and Application strategy. Hence, Case Studies of the company will be explored. Particularly, 5 construction projects of BAM

International will be investigated. These projects all involve a "Construct Only" type of contract, include BIM implementation but possess different working conditions and requirements from the client. Consequently, their investigation will offer to the researcher and the reader a thorough insight of the BIM usage in the building industry. This involves information regarding the procedures that are followed, the milestones and deliverables of BIM usage and the collaboration with the multiple parties as well. These Case Studies will be explored based on the data collected during the three rounds of interviews and the testimonies of the people worked in them. The objective of this step is to achieve a clear representation of the current conditions regarding BIM during the execution phase of a project.

The aim of the Case Studies is to provide the research with actual knowledge regarding construction projects. In this way, the suggested Framework will be applied to real situations. Moreover, the costs and benefits will be quantified based on the experience of the interviewees and the data they have available. These people will describe both the factors that facilitated the use of BIM and the barriers that hampered the implementation. Also, they will give a sufficient insight of the requirements from the side of the client and the relationship between the contractor and the other parties. Consequently, the costs of BIM that had to be covered by the contractor will be recorded. Moreover, an attempt to assign monetary value to the benefits gain will be achieved. This will be achieved based on the experience that the experts have by participating on each project in combination with the official technical reports of the company. This information will constitute the inputs of the framework. As a result, the output of the Framework will be the ratio between these two values which will be calculated on an Excel Spreadsheet for every Case Study.

1.5.6 Analysis & Synthesis of the Results

As aforementioned, the result of the Quantification of Costs and Benefits of BIM Implementation is the ratio between these two values. Following the calculation of the B/C ratio there will be an analysis of the result. This analysis will firstly involve the interpretation of the specific ratio. Moreover, there will be a CBA based on the specific conditions of each project. This analysis aims to comment on the costs that were required for the usage of BIM applications as well as the benefits that were gained among the 5 different projects. This comparison will help the researcher extrapolate some general conclusions regarding the implementation of BIM and the points where attention should be given by the contractor.

Following there will be a synthesis of the results. This synthesis will be based both on the numerical results that were gained by the Case Studies as well as the discussion with the experts about them. Therefore, this synthesis will clarify the impact that the results of the Framework have on the BIM strategies of the contractor as well as possible ways they could be employed in order to proceed with the BIM implementation in future projects and enhance the performance of the contractor.

1.5.7 Validation

In contrast to the previous stage, this step involves the application of the suggested Framework at the beginning of a construction project. To be more precise, the Framework regarding the costs and benefits of BIM will be used and followed as pilot in a construction project of the company which is at the initial stage. Thus, there will be an effort to record all the costs and profits regarding BIM on a standard basis, either daily or weekly. In this way, there will be accuracy in the calculations of them, assumptions will be avoided and even several intangible benefits will be quantified.

This step constitutes the validation of the Framework and aims to test the soundness of the proposed methodology. Particularly, each step will be applied carefully while the project execution phase is still in progress. This stage will check the accuracy of the quantification and relevance to the actual working conditions. The comments of the people that used the Framework constitute the validation of it. The validation is essential in the research in order to confirm the credibility of the results or make changes and improvements if needed. Hence, corrections and further suggestions on the functionality of the Framework will be requested from the people working on the specific construction project.

Eventually, a qualitative validation will also be aimed. This part will involve a short interview with people who work within the group of the contracting company, possess knowledge relevant to BIM but have not participated earlier in the research. Particularly, they will be thoroughly informed about the Framework and the findings of the research and then, the strategy that will be employed by the company regarding BIM, will be discussed. In this way, both the researcher and the reader will understand the impact the findings of the research will have on the strategy of the contractor.

1.5.8 Conclusions & Recommendations

The last phase of the research will focus on the conclusions emerging after the long investigation. This part will sum up the findings of all the previous stages and also answers the main research question. In addition, the researcher will make some recommendations based on the gaps of the research in order to reinforce the suggested method in the future. Also, this last part will cover the initial expectations of the research and their comparison with the results that she finally achieved.

Following, in Fig. 3, the structure of the thesis is shown as well as the connection with the Research Questions.

Figure 3 Structure of the thesis

1.6 BAM International Deployment BIM Strategy

As mentioned on section 1.5.5 the Framework will be applied on 5 construction projects of the construction company, BAM International. In this part a short description of this company is given in order to introduce the reader on the BIM strategies and the mindset they possess. BAM International holds an outstanding position in the international construction industry. BIM constitutes an innovative tool which can be seen as a competitive product. Therefore, the company has developed a deployment strategy regarding BIM and DC. Their main ambition is to add value to their company by using these innovative technological means and thus, improve the way they do things. Thus, the present research is carried out in collaboration with BAM International and aims to explore the Costs and Benefits of BIM Implementation of several construction projects on a worldwide level.

1.6.1 Mindset of BAM International regarding BIM and DC

The driving force behind this strategy is the ability to build something digitally and then on-site. This feature leads to a reduction in the amount of errors and optimises the construction process. Hence, based on a "Make it before we make it" mindset, the company focuses on these technological means. Particularly, BAM International strongly supports that DC improves the way is going things. Moreover, the shortcomings of 3D modelling and 4D planning bring people together. This contributes in adopting a pro-active mentality.

1.6.2 Vision of the company

The vision of BAM International concerning BIM and DC is that they should exist in every project. In this way, the company aims to create value with DC and is actively trying to find the benefits of this technological means.

However, the application of BIM and DC in every construction project is proven to be difficult. AEC industry constitutes a traditional field and the introduction of these tools is quite contemporary considering that BIM concept was introduced in the beginning of 90s and has been spread over the last 20 years. Thus, its recognition and adoption is very recent (Varghese, 2019, p. 2). Hence, the change from traditional techniques to innovative methods can be smoothened and managed properly. Consequently, as BAM International intends to do things better, they do not implement BIM as a standard but as a dynamic process based on the needs and conditions of the project.

1.6.3 Main objective regarding BIM and DC

The first and most important objective of BAM International regarding BIM implementation is to ensure a strong foundation in DC. In this way, the company can be prepared for the future. The first step is to code and handle the available data in every project. The foundations of BIM are thought to be essential considering that more and more innovative technologies are introduced in the AEC industry. The company intends to be a front-runner in the whole industry on a worldwide level including current projects in Dubai and Jakarta. Thus, BAM International aims at ensuring a competitive product out of these projects.

The plan of the company for the future is to implement BIM and DC more. In order to achieve this, they need to communicate to the stakeholders the importance of BIM and create awareness regarding the benefits of it. BAM International employees should realise that BIM and DC offer an actual monetary benefit to the company. Therefore, a thorough investigation of the costs and benefits of BIM in existing projects would remarkably help. Additionally, a standard method to quantify the benefits that BIM implementation brings to the contractor would be highly valuable. All the above, motivated the present study and the aim is to come up with a transparent method able to quantify the tangible and intangible benefits of BIM.

1.7 Research Scope

According to Turk, BIM philosophy is considered one of the most valuable technologies as it changes the way we design, build, use and manage the built environment around us. Thus, BIM is a powerful technological trend in the AEC industry which still triggers the interest for academic research (Turk, 2016).

The aim of this research is to provide Academia and Industry with a transparent and uniform approach evaluating the cost and benefits of the implementation of BIM. This procedure will define clearly the variables, inputs and outputs that are taken into consideration in order to apply the CBA. Moreover, the suggested method will be applicable in any construction project. The problems in the current evaluation will be detected and the steps leading to the solution will be described. The objective of this method is to substantiate the quantifiable benefits but also those which are more abstract and are eventually considered intangible. CBA was chosen in order to define thoroughly all the important data of each project to be investigated and identify clearly the positive and negative costs. In this way, the researcher will be able calculate their ratio and evaluate the inputs and outputs. The result of this research will verify the usefulness of BIM and how this technology benefits the construction industry.

2. Theoretical Background

2.1 Introduction

"What is BIM?"

According to Charles Eastman, "BIM is a digital representation of the building process to facilitate exchange and interoperability of information in a digital format". Regarding particularly the side of the contractor, BIM is considered the virtual building of a structure that consists of intelligent objects which when are shared among the participants of the project aim to enhance their collaboration and communication. Nevertheless, BIM is not only a software program but a software and a process. In other words, a 3D model alone cannot be considered as BIM. This innovative methodology should be accompanied by a new way of thinking and doing things which focuses mainly on managing information (Hardin, BIM and Construction Management, 2009, p. 3).

"Why BIM is not adopted by AEC industry with a faster pace?"

This question has assailed people working in the AEC industry since the first capabilities of BIM were introduced. It was not until the 1990s, when scientists started wondering which are the reasons that industry does not use this prime technology. The answers vary including a lack of relevant software, a lack of trained BIM personnel and a lack of a legal foundations that support collaborative work. On the other hand, others blame the conservative nature of the industry (Turk, 2016, p. 281)

While BIM techniques are under development, an examination of their benefits is required. This is a crucial issue in order to establish rationally BIM adoption in the AEC industry. In order to ensure this valid adoption, researchers strive for quantifying the costs and benefits that are generated by this innovative way of managing and creating information (Lu, Fung, Peng, Liang, & Rowlinson, 2014).

This chapter aims to introduce the reader to the concept of costs and benefits relevant to BIM Implementation. In addition, the reader will be presented a comparison between 2D traditional methods and BIM techniques. This comparison will be based on two SWOT analyses. At the end, the Research Sub-questions 1 and 2, will be answered by the researcher.

2.1 Costs of BIM

BIM implementation is considered to be accompanied with high costs. The perceived high initial cost of BIM has, however, discouraged numerous professionals within the AEC industry from employing it. Sometimes, the willingness of the owner to pay for BIM practices is critical in the decision of the contractor to use BIM methods (Giel & Issa, 2011). The challenges that come up in the procedure of measuring these costs deter the adoption of BIM methodologies. These costs are either direct or indirect. Indirect costs are definitely harder to be substantiated than the direct ones (Love, Simpson, Hill, & Standing, 2013).

2.1.1 Direct costs

On the one hand, direct costs are the ones that are associated to the implementation and operation of BIM (Love, Simpson, Hill, & Standing, 2013). These costs can generally be calculated and involve hardware, software (e.g. Revit, Navisworks, BIM 360 glue, Allplans, etc.) and installation costs. Thus, these costs depend on the level of detail of the model, the complexity of the project and the expertise and knowledge that the modellers possess. The level of detail (LOD) can be categorized through system published by AIA. LOD 100 refers to the concept. LOD 200 is approximate geometry phase. LOD 300 involves the accurate geometry phase. Following, LOD 400 is the stage of fabrication. Finally, LOD 500 is considered the as-built stage (Hergunsel, 2011) (See Fig. 4). In addition, according to Turk, there are currently three BIM maturity levels where BIM level 0 corresponds to information modelling of buildings using paper drawings, BIM level 1 to 2D and 3D CAD and only BIM level 2 and above to object-oriented representations of buildings and corresponding processes (Turk, 2016, p. 275). The level of BIM to be applied is established based on the needs and requirements of the client during the systems requirements planning stage. Accordingly, the required monetary amount for investment in BIM is generated.

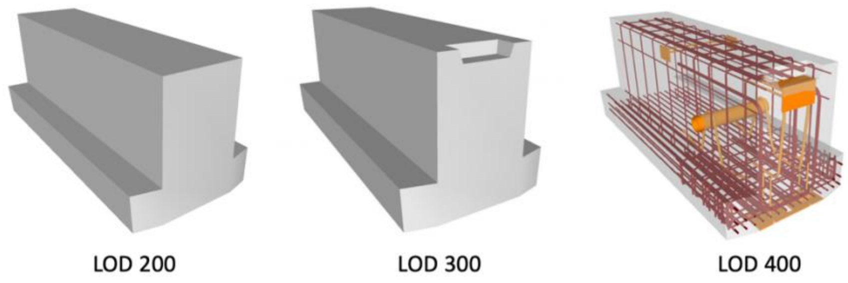

Figure 4 Levels of Detail (LODs) (Level of Development Specification Part I, 2019)

However, the estimates regarding direct costs which are formed initially can change later in time during execution. To be more precise, these estimates may significantly increase due to issues that emerge during the implementation such as interoperability, unexpected additional hardware that has to be acquired, expansion in the capacity of data storage and the inability of tools to connect non-3D and 3D data. Moreover, the costs that are needed for installation, configuration and maintenance issues can also be described as direct costs, and usually involve support from special technicians (Love, Simpson, Hill, & Standing, 2013, p. 214)

2.1.2 Indirect costs

On the other side, indirect costs are the costs which are have to do with the adoption of BIM. Indirect costs are considered to be of higher importance. Nevertheless, the abstract nature of these costs makes their identification and quantification quite challenging. Indirect costs involve organisational and human costs (Love, Simpson, Hill, & Standing, 2013).

Organisational costs emerge by the shift from traditional practices to the new way of working with BIM. The integration of a new technology usually causes a restructure within the organisation. The introduction of BIM is accompanied with a temporary loss of productivity because employees go through a learning curve while adopting new practices. Also, the training on BIM implementation which is required can be a challenge for construction firms because of the investment costs and the time required (Thurairajah & Goucher, 2013). This gradual adaptation might also involve training in order for the employees to acknowledge fully the potential of BIM. Another important factor that generates indirect cost refers to the management time. This time has to be spent in order to plan and organise the integration of recent technologies to the old approach of the company. The introduction of a new way of working undoubtedly comes along with changes in the already established strategies and plans of the company regarding the execution of the project.

Another indirect cost may emerge from the development of employees regarding BIM knowledge. Particularly, apart from training costs, BIM education might bring additional costs to the company. Training enhances the skills of the employees and as a result increases their contribution to the company. Consequently, employees might request a reward for their efforts. Moreover, considering the competitive nature of AEC industry, employees which acquired BIM knowledge may leave to join competitors if their requirements are not satisfied (Love, Simpson, Hill, & Standing, 2013).

2.2 Tangible & Intangible Benefits of BIM

There are some specific aspects of BIM that help in the effective implementation in project management (Diaz, 2016). According to Azhar et al. (2012), the contractors mostly employ BIM practices for the following applications; (a) Cost estimation and Quantity Take-off , (b) Early identification mistakes in the design due clash detections; (c) Construction planning and constructability analysis; (d) Validation on-the-spot on the construction site, guidance and tracking of the building activities; (e) Prefabrication outside construction site; (f) Planning to ensure health and safety; (g) Value engineering and employment of lean construction processes; (h) Enhanced communication among project participants. Hence, constructors, with the usage of BIM methods can achieve the following benefits; (a) High profitability; (b) Improved customer service; (c) Cost and time decrease; (d) Enhanced quality of the product; (e) Better decision making; (f) Higher levels of safety and management (Azhar, Khalfan, & Maqsood, 2012)

In fact, the benefits that BIM implementation brings to its users are either tangible or intangible. Tangible benefits refer to these which are quantifiable and can be associated to a monetary value. In contrast, intangible are the benefits which are more abstract and thus, are hard to be substantiated. Intangible benefits are hard to be quantified in monetary terms as their substantiation requires subjective estimations (Barlish & Sullivan, 2012).

The quantification of intangible benefits such as strategic competitive advantage that it gives to the contractor and the satisfaction of the rest other project participants, are insurmountable (Love, Simpson, Hill, & Standing, 2013). It should be mentioned that the returns that have been estimated by construction organisations can be less than the actual returns if intangible benefits are also taken into account. In other words, in reality, there are countless benefits that are abstract and if they were associated to a monetary value, they would increase the profit gained by the contractor. Given this lack of substantiation, AEC industry needs to nonobjectively think about the abstract benefits of BIM and how beneficial they can be to their business. However, the definition of the intangible benefits that can be generated BIM applications constitutes a vague task. Besides the importance of intangible benefits, there has been limited enlightenment on the quantification of this type of positive costs (Love, Simpson, Hill, & Standing, 2013, p. 212).

The development of a framework able to evaluation BIM implementation and does not restrict to quantification of costs and benefits should focus on the whole process. Understanding what is to be measured is fundamental to BIM evaluation (Love, Simpson, Hill, & Standing, 2013). Therefore, in this part, several of the numerous aspects of BIM will be explored. Furthermore, the tangible and intangible benefits that these applications offer to the contractor will be thoroughly analysed. This analysis will introduce the reader to the capabilities of this innovative technology and will provide a sufficient understanding regarding the objective behind and the foundations of the framework.

2.2.1 3D Modeling

The 3D model of BIM technology facilitates collaboration and enhances the whole implementation of the project by providing visual controls during the execution phase. The AEC industry has remarkably gained benefits regarding the 3rd dimension of BIM, such as improved communication and saving of time and cost (Charef, Alaka, & Emmitt, 2018, p. 242).

- Visualisation: This aspect of BIM provides the project participants with a better understanding of the procedure. Also, immediate visualisation of forms and alternative solutions can be easily evaluated by professionals and non-technical staff at the same time (Manning & Messner, 2008). This facilitates the communication among the stakeholders regardless their role in the project. Moreover, 3D models can be analysed in depth, simulations can be realised fastly and the performance of each simulation can be assessed (Ahankoob, Khoshnava, Rostami, & Preece, 2012). All these benefits can eventually speed up the progress of the execution.
- Improved Collaboration: Another popular advantage of BIM is the increased collaboration among the members of the project team, which is achieved thanks to a centralised model (Thurairajah & Goucher, 2013). This central model can be a Common Data Environment (CDE) which helps the information management and sharing among the participants. Consequently, the collaboration and communication among participants is facilitated. Furthermore, increased collaboration leads to increased profitability, efficient management of time, and improved relationship between the client and the contractor (Azhar S. , 2011)
- Quantity Take-off (QTO): The 3D models that are developed in BIM software involve sufficient data and are able to link individual elements with the material they represent in the model. This feature gives the ability to speed up the Quantity Take-Off procedure for a construction project and at the same time improve the reliability of the estimate. In this way, materials are not overordered and extra costs are avoided (Olsen & Taylor, 2017).
- Waste Reduction: BIM is one of the modern technologies which succeeds in reducing waste. Construction waste is mostly produced due to design changes and errors, leftover materias, no recyclable or re-useable packaging waste and poor weather (Liu, Osmani, Demian, & Baldwin, 2011). 3D model leads to more accurate QTO than those calculated by hand. Therefore, at the end of the execution there are less materials leftover going to waste. In addition, the ability of BIM is to identify future clashes in the initial phase of a project. As a result, rework is avoided and the ordered quantities of materials are used effectively.
- Clash Detection: According to studies, this aspect constitutes the main way by which owners reduce time and cost thanks to BIM. Normally, in 2D drawings, the modifications that are made in one drawing the other relevant drawings are not immediately updated. This leads to many inconsistencies and hence lots of mistakes and defficiencies. The majority of these mistakes are identified only at the construction site, and then might lead to numerous conflicts and change orders. However, BIM methods deal with these issues by preventing future mistakes. Particularly, the early identification of mistakes accelerates the execution of the project, reduces costs, and minimises legal misunderstandings (Ahankoob, Khoshnava, Rostami, & Preece, 2012).
- Federation of the model: The core of BIM practices is a shared database for the project, assigned to the 3D model, which constitutes the foundations for the complete project documentation (Czmoch & Pekala, 2014). Thus, the model is integrated and architecture and structural design are being implemented on the same model. Consequently, their overlapping is reduced and future mistakes are avoided because clashes are detected before they happen on site (Ahankoob, Khoshnava, Rostami, & Preece, 2012).

- Coordination: Visual representations enhance communication among the stakeholders of the project and facilitate brain-storming. Moreover, when they are used efficiently they can provide effective and and multi-disciplinary feedback to the project team (Russell, Staub-French, Tran, & Wong, 2009). As a result, the project team achieves a reliable and smooth performance.
- As-built Drawings: As-built drawings are created at the end of the construction phase. Their purpose is to record the state of the facility at the time of the delivery (Clayton, Johnson, Song, & Al-Qawasmi, 1998). During the process of the execution, the 3D model is constantly updated according to the design changes. Thus, when the project is completed, the model includes all the details and the important information needed by the client. In addition, it is accurate because the information was recorded on the spot and was taken from the source. Therefore, the as-built drawings are of higher quality comparing to traditional 2D as-built drawings.
- Cost Estimation: According to studies, cost estimates that are based on BIM models can significantly reduce the work of the estimators and the possible errors which are involved in conventional methods of cost estimation. Researchers have figured that cost estimations which are based on 3D models have brought better results over conventional practices. Furthermore, it was proven that the more complex the estimation was, the more obvious were the advantages of using BIM models instead of conventional estimating techniques (Li, et al., 2014, p. 3).
- Common Data Environment (CDE): This concept constitutes an environment to share work and information efficiently among different disciplines and. at the same time, maintaining integrity of the model (Sacks, Gurevich, & Shrestha, 2016, p. 487). This methodology indicates how information should be managed with the usage of BIM and CAD processes (Migilinskas, Pavlovskis, Urba, & Zigmund, 2017, p. 1087). This information regards the building accompanied by other parts, elements and activities associated to it (Hardi & Pittard, 2015, p. 367).

2.2.2 4D Planning

The visualisation that accompanies the 3D model of BIM was not sufficient. Thus, in order to ensure faster delivery, the time factor evolved rapidly as the 4th dimension of BIM (Charef, Alaka, & Emmitt, 2018). Generally, researchers refer to 4D as the integration of information related to time (Lopez, Chong, Wang, & Graham, 2016). The planning of construction with the use of 4D CAD involves the linking between a plan to the 3D objects of the model. This allows to create a simulation of the construction process and indicate what the building and construction site would be like at any moment. This visual simulation offers useful insight to the construction procedure on a daily basis and provides evidence about potential problems such as space conflicts and points for improvements regarding safety etc. (Eastman, Teicholz, Sacks, & Liston, 2008).

- Sequencing: BIM can be employed in order to build an accurate schedule of material ordering and delivery of all the elements of a building. Accurate time scheduling facilitates on-time delivery of materials and equipment and at the same time, eliminates the possibilities for damages (Ahankoob, Khoshnava, Rostami, & Preece, 2012). Hence, interfaces are managed properly during the execution on the construction site. Moreover, the real-time information of the predecessors and successors of each activity and their impact on the critical path, which is visually provided by the the 4D model, is necessary to inform sufficiently the project stakeholders regarding the progress. In addition, real-time viewing helps to ensure the on-time completion date (Lopez, Chong, Wang, & Graham, 2016).
- Monitoring: The 4D model also allows the team to confirm the time planning and to detect mistakes in the logical link among activities (Ciribini, Mastrolembo Ventura, & Paneroni, 2016, p. 71). Therefore, conflicts are detected and resolved on time and this ensures time efficiency.

Additionally, the visual representations of the schedule of a project and the relevant information in combination with visual representations of the progress of the project can provide further benefits. To be more precise, they can help in forming effective construction strategies in order to shorten the project duration, assess their constructability, and evaluate the overall quality of the schedule (Russell, Staub-French, Tran, & Wong, 2009, p. 219). Finally, 4D model illustrates the layout of the construction site and equipment and materials are exactly placed. This feature eliminates the amount of additional handling, unnecessary movements and the possible loss of materials (Ahankoob, Khoshnava, Rostami, & Preece, 2012).

- Constructability: The soundness of drawings affects the constructability of a structure. Nevertheless, this is not enough and construction works and performance on site should be thoroughly investigated in order to reach a successful result. The visualisation of the model, the reports of the elements and the schedules that are extracted from BIM can be used to affect constructability and change parameters that influence the correctness of building elements and (Tauriainen, Puttonen, & Saari, 2015). The benefit of these applications is that the team ensures that the project is constructable and the result will apparently be successful.
- Visualisation: 4D model provides visual representations of the 3D model in combination with the time schedule. These representations are considered to be significantly effective as they provide clear view of the progress of construction. As a result, the client can be fully informed and gain clear understanding of the progress. This brings his satisfaction and increases the rate of acceptance of any possible project changes or time delays.

2.3 SWOT Analysis

BIM constitutes a recently introduced tool in the field of AEC industry (Walaseka & Barszcz, 2017). Therefore, like every innovative tool, it is still faced with concerns, doubts and difficulties from the side of the designers, contractors and users in general. As a result, the adoption rates of this technology have been lower than anticipated. Numerous obstacles that hamper BIM implementation have been identified (Walaseka & Barszcz, 2017). Consequently, in order for this tool to be adopted smoothly by people working in this industry, the advantages and disadvantages that characterise it should be defined and properly evaluated. Hence, this chapter aims to present and analyse the strengths, weaknesses, opportunities and threats of the traditional methods and those of BIM in the project execution phase. In this way, the reader can be introduced to the perks that BIM can offer compared to the techniques that have been used so far.

SWOT Analyses contribute in the research by clearly indicating the characteristics of both methodologies. Moreover, they constitute the foundations for the evaluation that follows because they provide the theoretical background regarding the advantages and disadvantages of each method. Initially, a SWOT Analysis of the conventional 2D methodologies is completed in order to describe their strengths which justify the hesitance of the AEC industry to adopt new techniques. At the same time, the weaknessess and threats of them can prepare the reader for the benefits that accompany BIM applications. Consequently, the SWOT Analysis of BIM methodologies highlights the strengths that they can offer to the industry which can be considered as benefits. In contrast, the weaknesses such as the high cost of implementation intrigue the researcher to dive into their evaluation. Furthermore, the interest in AEC industry towards BIM in combination with the threat that the lack of substantiation of costs and benefits poses, amplify the need for an evaluation. Hence, the researcher is inspired and encouraged to delve deeper into this topic and propose an evaluative method regarding BIM implementation in construction.

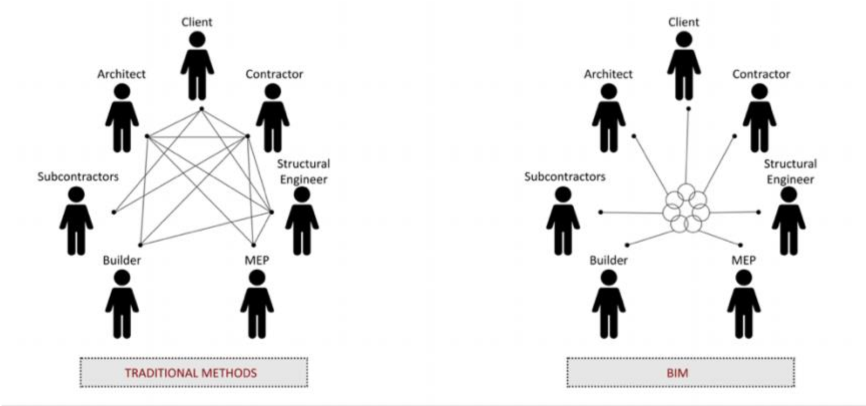

Figure 5 Difference of traditional and BIM methods

2.3.1 SWOT Analysis of Traditional Methods

BIM represents an evolution from conventional 2D design methods, as models are developed through the combination of 3D graphical modelling, 4D time modelling and 5D cost modelling (Thurairajah & Goucher, 2013). The traditional methods of project execution and project management are accompanied with multiple advantages. This is the reason they have been employed for so many years. In addition, their principles constitute the foundations of any innovative technology. These methods can be mixed within the conventional design and execution phases. So far, and for many years traditional methods have been employed both in design and construction phase of the projects. Undoubtedly, these methods are accompanied by advantages and challenges.

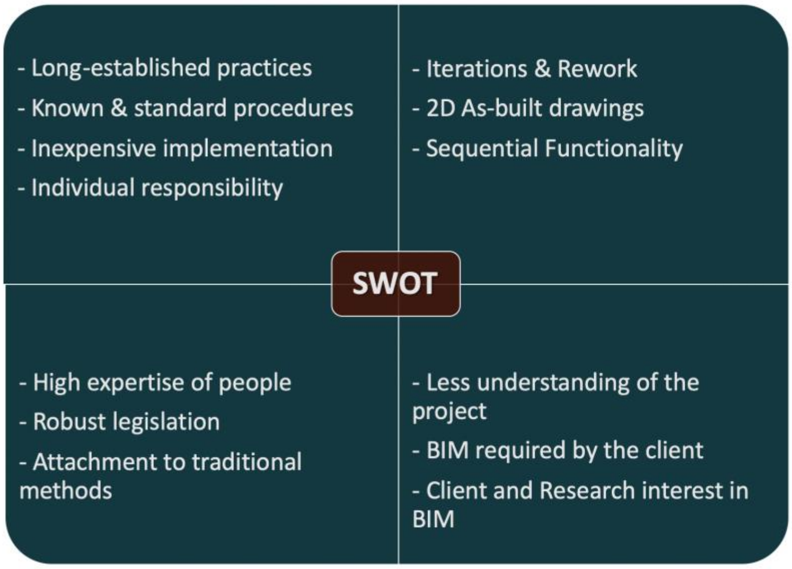

Figure 6 SWOT Analysis of traditional methods

Strengths

- Long-established practices: The conventional project management method has been proved efficient to deliver the product required from the customer for a long period of time. The outcome is that the client is satisfied. In general, when a strategy regarding the execution phase of a project is productive, helps the company and the client grow a relationship of trust and understanding. As a result, this strategy is used in future projects too. Moreover, it has a positive influence on the employee, as he gains experience and he is able to perform complex activities and to accomplish challenging tasks (Sid, 2020)

- Known & Standard Procedures: The conventional techniques of structural design have been developed for centuries and have remained the same. So far, the projects were based on 2D drawings (plans, sections, elevations) and the building was designed in a symbolic manner, in accordance with the principles which are agreed by all the project participants (Czmoch & Pekala, 2014, p. 211). Therefore, people working in the construction industry are used to these procedures. This does not actually encourage their transition to BIM. They are not confident with it and feel fear that this method would lead to too low success or a big failure. In additon, another barrier in the implementation of BIM is that normally the senior leadership of the company is in favor of conservative approaches that involve known procedures (Migilinskas, Popov, Juocevicius, & Ustinovichius, 2013).
- Less expensive implementation: The traditional practices are doubtlessly the most suitable regarding small and medium sized projects because they involve low cost as the most important benefit (Czmoch & Pekala, 2014, p. 214).
- Individual responsibility: In the traditional methods each of the professionals work on individual drawings including only the parts of their responsibility (Czmoch & Pekala, 2014, p. 211). As a result, when problems occur during project execution, the person responsible for that collision is addressed. However, in BIM, data is inserted in the model and information is shared among all the parties. Therefore, an issue that emerges is who will monitor the entry of information into the model and be responsible for any inaccuracies (Azhar S. , 2011).

Weaknesses

- Iterations & Rework: Traditional methods involve numerous iterations in order to reach the final result. CAD software facilitates the conclusions, but still engineers have to create a separate structural model for each different architectural concept in order to implement static calculation and further analysis which is required. When on-site is decided that something has to be changed then the 2D drawings both in architectural and structural design have to be updated. These reworks lead to time delays for the project execution (Czmoch & Pekala, 2014, p. 213).
- 2D As-built Drawings: The costs of as-built drawings constitute some of the costs that change because of the use of innovative technology. Hence, this enhanced and innovative application of technology may bring decrease in the cost of producing 2D as-built drawings (Clayton, Johnson, Song, & Al-Qawasmi, 1998). As mentioned, the 3D model is finalised and updated during the construction phase, according to the corrections that are made. Therefore, when the project is completed, 2D as-built drawings can be extracted fast and without additional cost. Sometimes revision is required in order to establish the as-built information needed to support the future stages. This retroffiting can be expensive. This happends because of a lack of coordinated effort during the previous phases to arrange the essential as-built information which is needed for the accurate and safe operation and maintenance of a facility (Liu, Stumpf, Kim, & Zbinden, 1994).
- Sequential Functionality: Traditional methods require each stage to be executed individually. For example, the structural designer has to wait until the architecture has completed the 2D drawings in order to proceed with the structural analysis. In addition, cost estimations cannot be performed before the final drawings are provided. The conventional process involves the completion of the design in a particular stage and following freeze further design until an estimate is achieved and permission is given in order to advance to the following design phase (Mitchell, 2012).

Opportunities

- High expertise of people: As already mentioned, traditional methods have existed and been employed by people working in AEC industry for years. Consequently, an unequivocal value of the traditional methods, is that the designers who possess the highest expertise have applied this approach for many years (Czmoch & Pekala, 2014, p. 214).
- Robust legislation: Drawings were the primary means of communication in the construction industry for centuries, and many professional organizations had developed standards and guides for these working procedures. The American Institute of Architects (AIA) CAD standards were among those developed in the early 1990's Eventually, national and international CAD standards such as BS 1192 (BSI, 2007) and ISO 13567-2 (ISO, 1998) were broadly adopted, resulting in industry wide standardization in CAD drawing production (Sacks, Gurevich, & Shrestha, 2016).
- Attachment to traditional methods: BIM methodologies face remarkable barriers because individual professionals and companies in AEC industry have established their CAD efforts in conventional and non-parametric tools for years. As a result, most of them are now adverse to modify their way of working (Manning & Messner, 2008).

Threats

- Less understanding of the project: Another important lack of the conventional methods has to do with the ability to visualise and to deeply understand the relationships between activities, including possible errors that may occur later on the construction site. Normally, the construction site is illustrated with the use of 2D CAD drawings that are not attached to the time schedule. This makes it hard to understand the development of the construction site layout in relation to the construction progress (Ciribini, Mastrolembo Ventura, & Paneroni, 2016, p. 69). As a result, the project team is not properly prepared for the project execution phase and problems that lead to time delays often occur.
- BIM required by the client: In order to expand the adoption of BIM within the AEC industry, clients have tried to use their influence and require BIM. Consequently, the question shifts from: "Whether or not to use BIM", to "How it should be used in the specific project" (Lindblad & Rudolphsson Guerrero, 2020). In addition, powerful construction clients such as companies, public authorities and governments, understand the need to facilitate and support adoption of BIM for their projects because they gain important benefits from its use in numerous phases of their life-cycle (Sacks, Gurevich, & Shrestha, 2016).
- Client and Research Interest in BIM: At the same time that BIM technology continues to expand within the AEC industry, it has also trigger the interest on the side of the researchers (Liu, Lu, & Chang Peh, 2019). Moreover, the AEC industry requires enhanced communication and collaboration among participants based on the interoperability of information. BIM is predicted to be a potential solution to these problems, and hence, a way to grow productivity (Lu, Fung, Peng, Liang, & Rowlinson, 2014). Therefore, researchers, instead of expressing doubts and highlighting the incapacities of BIM, they often request a change of mindset within the AEC industry in order to face the constraints and achieve proper implementation of BIM methodologies (Koutamanis, 2020).

2.3.2 SWOT Analysis of BIM

In this part a SWOT Analysis of this recent methodologies will be conducted. The aim of this SWOT Analysis is to clarify the Strengths, Weaknesses, Opportunities and Threats of BIM which accompany the transition from the traditional practices to the innovative ones. In many aspects, in comparison to

2D methods, BIM is beyond comparison, since BIM integrates all information which results in enhanced collaboration among disciplines, more rapid update of the project, and also brings effective clash detection and more accurate bill of quantities as well as cost estimation (Czmoch & Pekala, 2014).

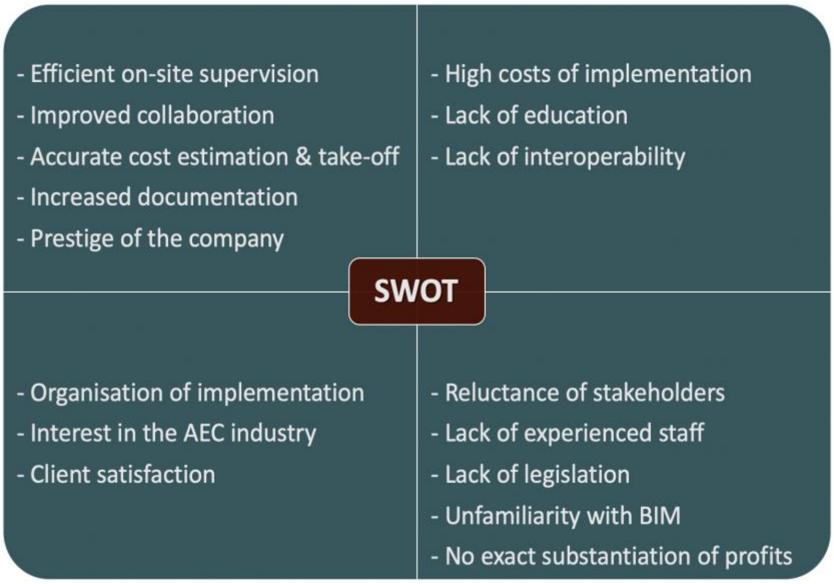

Figure 7 SWOT Analysis of traditional methods

Strengths

- Efficient on-site supervision: BIM methods enhance the on-site supervision of the project team as it ensures saving of time and avoidance of mistakes. To be more precise, the comparison between the as-planned and as-built progress according to BIM can provide the construction executors and supervisors, as well as other participants who do not possess engineering knowledge such as the clients, with important information regarding a variety of crucial issues. For instance, these issues can include constructability reviews, safety checks and proactive schedule optimisations (Li, et al., 2014, p. 3).
- Improved collaboration: The 3D model of BIM remarkably enables collaboration not only between the architect and the structural engineer but among the project participats as well. To be more precise, a 3D model prepared by an architect can be efficiently reformed to the analytical model that constructor can use for the structural analysis. Particularly, the structural engineer can simply acquire the data regarding the structural behaviour and proceed with the checking of building code requirements. Moreover, the architect can simply review the cost for each conceptual design which has been already confirmed by the structural designer (Czmoch & Pekala, 2014, p. 213). Furthermore, BIM makes the transition from the traditional paper-based tools of construction projects, into a virtual environment and brings a level of efficiency, communication and collaboration which exceeds the ones that accompany the traditional construction procedures (Bryde, Broquetas, & Volm, 2013).
- Accurate Cost Estimation & Take-Off: According to studies, the employment of BIM enhances the cost estimation accuracy within 3% as compared to traditional estimates (Azhar S. , 2011, p. 243). Hence, cost estimation using BIM Quantity Take-Off is considered to be more accurate than when it is done with traditional methods (Sacks, Gurevich, & Shrestha, 2016). This also ensures the avoidance of errors regarding the material quantities and over-ordering. As a result, there is reduction in waste and cost.

- Enhanced documentation: The most important difference between BIM techniques and conventional 3D CAD is that the latter presents a building by independent 3D views such as plans, sections and elevations. Consequently, in order to edit these views, all of them should be checked and updated. This constitutes an error-prone process which is one of the main causes of low-quality documentation. Moreover, the data included in these 3D drawings are only graphical entities only, such as lines and circles, in contrast to the semantics that BIM models consist of. In these models, objects are defined in terms of building elements and systems such as spaces, walls, beams and columns. Hence, a BIM contains all the information relevant to the building, regarding its physical and functional characteristics as well as project life-cycle information (Azhar, Khalfan, & Maqsood, 2012). In other words, BIM can be fundamentally described as a data package as it involves essential information about design, execution and management of the building (Diaz, 2016, p. 3).
- Prestige of the company: Contractors refer to the enhancement of the company's image as one of the top internal benefits of BIM (McGraw Hill Construction, 2014). In fact, in a competitive market as the AEC industry, construction companies endeavour a leading position. Thus, they should adapt to the innovations and be constantly up-to-date. In this way, they can offer competitive products to their clients. Considering that BIM constitutes a developing technology, its implementation enhances the image of the company. Moreover, the adoption of BIM establishes the position of the contractor among its competitors and adds value to his services.

Weaknesses

- High cost of implementation: Nowadays, considering the high cost of implementation, the application of BIM is profitable mostly for large projects. If the cost software and hardware decreases, the accessibility of BIM would extend to smaller projects (Czmoch & Pekala, 2014, p. 215). The hardware that is required in order to supporti BIM applications is much more expensive than this for CAD applications, due to the large size of BIM files and the higher graphic requirements (Zima, Plebankiewicz, & Wieczorek, 2020). In addition, the implementation of BIM often requires the acquisition of new equipment. It should be remarked that based on surveys, a possible reason that BIM implementation might not be encouraged is the high cost of the required equipment.
- Lack of education: In order to attain a successful BIM implementation it is crucial that the members of the project team possess sufficient knowledge. Nevertheless, the education of clients can also be another remarkable barrier. When people belong to the industry, they can be educated, but when they do not, some other strategies need to be considered. Hence, academia has begun teaching BIM implementation and has arranged courses to integrate BIM into contemporary programs relevant to the AEC industry (Silverio, Suresh, Renukkapa, & Heesom, 2016). Considering that BIM is essentially reshaping the organisation of building processes, workflow, contractual arrangements and legal relations, courses on collaboration, management, construction law, and cost estimating should prepare students for this new reality in the AEC industry (Turk, 2016, p. 280).
- Lack of interoperability: Interoperability constitutes the ability to exchange data between applications to facilitate automation and avoid the re-entry of data (Azhar, Khalfan, & Maqsood, 2012). The majority of project participants are used to work with specific tools regarding the software and hardware and often the transfer of data is limited due to incompatibility. As a result, the transmission of the consistent and accurate information to other participants is not facilitated. To be more precise, the data that is not transferred needs to be recovered and hence,

additional efforts need to be made (Migilinskas, Popov, Juocevicius, & Ustinovichius, 2013, p. 773). Thus, it should be remarked that the users must ensure interoperability when they choose BIM software applications (Azhar, Khalfan, & Maqsood, 2012).

Opportunities

- Organisation of implementation: The lack of specific standards for the intregration of the 3D model and the management by multidisciplinary group does not make BIM implementation easier. The incorporation of multidisciplinary information into a single 3D model requires establishment of protocols during the preparation stage in order to ensure consistency in BIM. Nowadays, considering that there are no standard protocols available, each company adopts its own. Concequently, this could cause inconsistencies in the model and if these are not properly detected, they could then lead to inaccuracies. In addition, BIM coordination can enhance the communication among team members. However, such an essential modification in the culture of AEC industry cannot be realised only by technology. The cooperation among stakeholders strongly depends on the management of relationships within the project team (Rowlinson, Collins, Tuuli, & Jia, 2009). Hence, BIM protocols & standards should be created within the company in order to encourage its adoption and establish clear guidelines regarding its usage.
- Interest in the AEC industry: Many well-established companies, including both contractors and investors, that are leaders in AEC industry are highly interested in the usage of BIM methods due to their wish to reduce the costs of construction investments and to enhance the prestige of their company (Zima, Plebankiewicz, & Wieczorek, 2020, p. 9).
- Client satisfaction: Numerous client organisations claim that BIM should be implemented in their design and construction projects. To be more precie, some clients directly lead the implementation, training, and management of the BIM technology. In contrast, other clients ask consultants to offer BIM solutions for each project. In this case, the architects, engineers and contractors appoint independent BIM Consultants to support the planning and management process (Rowlinson, Collins, Tuuli, & Jia, 2009).

Threats

- Reluctance of stakeholders: During the realisation of a BIM-based project, some project participants cannot appreciate the potential of this technology. As a result, the client has to convince or even force the other stakeholders to use BIM (Hadzaman, Takim, & Hadi Nawawi, 2015). Moreover, there are many reasons refraining project participants using innovative technology and specifically, BIM methods. Particularly, they might be afraid of the result, the high costs of the initial investment, and the time that is required in order to learn how to use the software (Migilinskas, Popov, Juocevicius, & Ustinovichius, 2013, p. 773).
- Lack of expertise: Some studies have declared that there is lack of qualified BIM professionals in the AEC industry. This constitutes a significant barrier in the adoption of BIM (Silverio, Suresh, Renukkapa, & Heesom, 2016). Even though there is available revelant software on the market, there are only a few specialists able to design correctly a BIM in accordance with world standards (Zima, Plebankiewicz, & Wieczorek, 2020, p. 8).
- Lack of legislation: Nowadays, there is no special legal legislation regarding BIM implementation. This can lead to misunderstandings on the investor-designer-executor line. Following, such conflicts can cause time delays on the construction site, generating additional cost. Additionally, this lack of legal legislation regarding BIM can cause unwanted results like an unfair distribution of costs and benefits which would not establish correctly the implementation of BIM (Czmoch &

Pekala, 2014). Moreover, another significant barrier which hampers the use of BIM is the lack of information regarding the accurate BIM rules for specific stakeholders as well as the contract obligations (Migilinskas, Popov, Juocevicius, & Ustinovichius, 2013, p. 773). Considering the benefits that can be obtained through BIM, client organisations feel the need to boost the adoption of BIM. Therefore, a potential tool to attain this acceleration is to establish policy frameworks expressed in the form of national standards, collaboration guidelines and project-level BIM execution plans (Sacks, Gurevich, & Shrestha, 2016).

- Unfamiliarity with BIM: Another barrier in the BIM implementation during project execution could be considered the unfamiliarity that characterises its users with BIM's abilities and depth (Manning & Messner, 2008). In addition, usually problems are found to lie with users: their incapacity or unwillingness to adopt BIM; lack of BIM knowledge; lack of trust in each other's models and generally limited or superficial application of BIM (Koutamanis, 2020). According to studies, many project participants show reluctance in coordinating their own work and in collaborating in order to effectively implement BIM in the design and construction phase of the project (Ciribini, Mastrolembo Ventura, & Paneroni, 2016, p. 71).
- No exact substantiation of profits: Based on studies, many people in the AEC industry are not aware about the impact, either positive or negative, that BIM has on the profitability of projects in their company. The main reason is that their companies do not actively record the effects of BIM implementation (Qian, 2012). Considering that the usage of BIM in actual construction projects has not been intensively explored and there is a lack of established proof of BIM's benefits in relation to the outcome of the project, stakeholders still face the dilemma of deciding whether or not employ BIM methods (Li, et al., 2014, p. 3).

2.3.3 Need for Evaluation of Costs and Benefits of BIM

Both SWOT Analyses helped in building the foundation for the evaluation of the positive and negative costs of BIM. This theoretical background of traditional methods and BIM techniques makes the evaluation of BIM more comprehensive and robust. Particularly, the Threats of BIM methodologies and specifically, the unfamiliarity with BIM, the reluctance of the stakeholders and the lack of substantiation of costs and benefits cause the need for standard procedures and a transparent method of evaluation. Therefore, the present research which involves the development of an evaluative method aims to counter with these Threats and raise awareness regarding BIM implementation within the AEC industry.

More precisely, one of the threats refers to a lack of the exact substantiation of the profits of BIM constitutes a highly interesting issue for Academia and Industry as well. So far, financial tools such as ROI have only been used to explain the employment of BIM by simply quantifying the costs and benefits that emerge. However, offering decision-makers information relevant to direct cost analysis, cash flow projections, and financial assessments does not consider the indirect and intangible costs and benefits which are associated with BIM implementation. As a result, there is no evaluation of the actual worth of the technology. Consequently, an evaluation approach for BIM that is not restricted to the conventional limits of financial evaluation is needed (Love, Simpson, Hill, & Standing, 2013).

In the context of Information Systems (IS) the term evaluation defined as "a process that places different points in time or continuously, for searching for and making explicit, quantitatively or qualitatively all impacts of an IS project" (Love, Simpson, Hill, & Standing, 2013). With this definition in mind, CBA constitutes the procedure that will manage to consider both direct and indirect costs along with tangible and intangible benefits. Therefore, the analysis will be twofold in order to include not only the quantifiable positive and negative costs but these of more abstract nature as well.

Initially, the evolution of BIM and the investigation of its costs and benefits were inseparably linked. This relation is explained considering that if the aim of a technology is to survive in a competitive market it must possess a robust economic ground which will be accurately comprehensive (Lu, Fung, Peng, Liang, & Rowlinson, 2014).

2.4 Conclusion

In this chapter the researcher defined the direct and indirect costs which are associated to BIM Implementation as well as the tangible and intangible benefits that stem from the usage of BIM applications according to the published literature. Furthermore, she analysed thoroughly the characteristics of traditional methods and BIM based on SWOT analyses. Hence, after reading this chapter, the following Research Sub-questions can be answered.

> ***Sub-question 1:*** *Which are the costs and benefits associated to BIM implementation?*
> ***Sub-question 2:*** *Which unique characteristics of BIM (in comparison to traditional 2D methods) warrant an evaluation into its added value?*

Regarding the first Sub-question, the costs and benefits that stem from the usage of BIM are analysed in detail. On the one hand, the costs that are shown on Fig. 8, can be either direct and include the cost of software, hardware and installation or indirect which involve the costs required for the adoption of BIM. These mainly refer to the costs which are required in order to integrate this technology within the operational context of a company. On the other hand, the benefits can be either quantifiable or have an abstract nature which is hard to be quantified. These benefits are produced by the employment of the 3D Model as well as the 4D Planning and are presented in detail in Fig. 9.

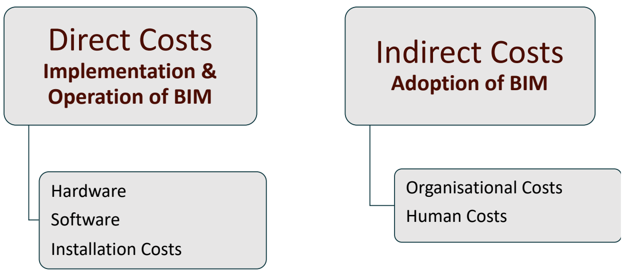

Figure 8 Costs associated to BIM Implementation

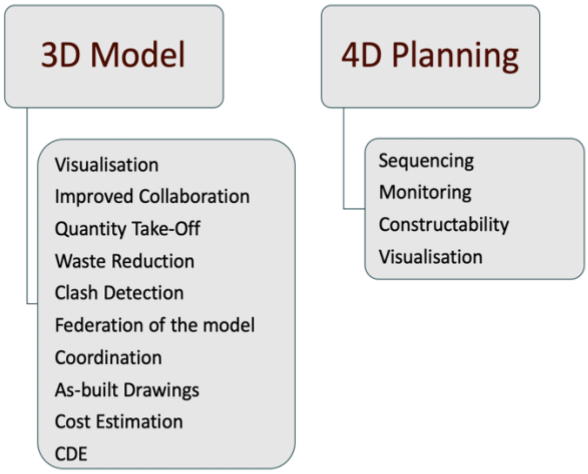

Figure 9 Benefits associated to BIM Implementation

With regards to the second Sub-question, the researcher carried out two separate SWOT Analyses in order to indicate thoroughly the characteristics of each methodology. The aim of these analyses was to make clear the differences between these ways of working and make the reader understand reasonably why the evaluation of costs and benefits of BIM is needed. When the SWOT Analysis for BIM was completed, the researcher could point-out the characteristics of BIM that cause the need for an evaluation. Particularly, the following special characteristics of BIM in comparison to 2D traditional methods amplified the need for evaluation.

Firstly, the Strengths that are presented on Fig. 7 and include the Efficient on-site Supervision, Improved Collaboration, Accurate Cost Estimation and Take-off, Enhanced Documentation as well as the Prestige of the Company, constitute the most significant benefits that BIM methods offer that intrigue deeper investigation. Following, the first Weakness that is mentioned and involves the High Cost of Implementation motivates the reader to dive into this cost and evaluate it in comparison to the benefits mentioned above. Nevertheless, it should be admitted that the most important characteristics of BIM that warrant the evaluation that the proposed method will provide are the Threats. Particularly, the Reluctance of the Stakeholders, the Unfamiliarity with BIM and the Lack of exact substantiation of the profits constitute the Threats that the evaluation method aims to encounter. The main purpose is to evaluate the costs and benefits and thus, raise awareness regarding BIM methods.

3. Cost and Benefit Analysis Framework Development

3.1 Introduction

While the benefits of BIM have been broadly espoused and its adoption is becoming a main part of many government's strategies to achieve better value for money (VfM) from their assets, many private clients as well AEC companies are sceptical of the remarkable financial investment that is required in order to implement this new and innovative technological methodology (Love, Simpson, Hill, & Standing, 2013)

BIM adoption in the AEC industry needs strong foundation. To ensure this foundation, researchers have made efforts to substantiate the positive and negative costs that are generated by this pioneer technology. The main challenge is that the costs and benefits of BIM are hard to specify and even more demanding to quantify. This is undeniable considering that BIM is being increasingly integrated into managerial aspects of AEC projects, such as enhancing communication and facilitating collaboration. Another barrier of this quantification is that data concerning BIM implementation in the industry are not readily available. Furthermore, the existing measuring tools have been designed in a scorecard way, asking BIM users to report costs and benefits (Lu, Fung, Peng, Liang, & Rowlinson, 2014, p. 318).

These tools are useful because they directly involve BIM users and encourage them to accurately examine costs and benefits. Nevertheless, a significant drawback is that they rely mainly on the experience of users. Thus, most of the times, these methods underestimate or exaggerate the costs and benefits generated by BIM methods (Lu, Fung, Peng, Liang, & Rowlinson, 2014, p. 318). The reason of these inaccuracies is the lack of on-the-spot information. Therefore, the mixed perspectives and opinions on the costs and benefits of BIM cause misunderstandings regarding its expected outcomes.

The second challenge is to recognise the benefits of BIM. Several studies have already explored the benefits of BIM implementation, which involve for instance, better communication, early collaboration, error-free design, less rework, better predictability, saved cost, and improved productivity (Lu, Fung, Peng, Liang, & Rowlinson, 2014). This difficulty is amplified by the fact that BIM offers mostly intangible advantages which are hard to substantiate such as improved collaboration, safety, risk and waste reduction as well as higher quality.

3.2 Cost and Benefit Analysis

A CBA is an overview of all the positive effects (benefits) and negative effects (costs) of a project. The costs and benefits are quantified and valued in monetary terms. Also, the benefits and costs are defined in terms of change of human welfare or utility and are measured by individuals' willingness-to-pay for a benefit and willingness-to-accept for a cost (Hwang, 2016).

3.2.1 Theory of CBA

CBA is a policy assessment method that quantifies in monetary terms the value of all consequences of a policy to all members of society. In general, CBA applies to policies, programs, projects, regulations and demonstrations. Due to this large spectrum, CBA can provide a strong baseline for the evaluation of the costs and benefits of BIM implementation. The CBA procedure involves the nine following basic steps which are briefly described (Mouter, 2014).

1. Specify the set of alternative projects: This step involves the listing of the alternative cases that the analyst will investigate. This stage is considered demanding because it can include a large number of alternative cases. The aim of CBA is to estimate the Net Social Benefits (NSB) of the potential projects.
2. Decide whose benefits and costs count (standing): This step requires from the analyst to decide which factors have standing; meaning whose costs and benefits count and should be taken into consideration.
3. Identify the impact categories, catalogue them, and select measurement indicators: This step involves the definition of the physical impact categories of each alternative. Particularly, the analyst must catalogue these impacts as benefits or costs and also define their measurement indicator. The term impacts represents both an input or an output. Subsequently, the aim of this step is the clear and comprehensive definition of inputs and outputs for the CBA to be conducted.
4. Predict the impacts quantitatively over the life of the project: Considering that almost all projects have impacts that extend over time, the analyst has to quantify all the impacts in each time period. However, this step is difficult especially when projects are unique, have long time horizon and possess complex relationships among their variables. Along with these, projects possess different size, scope and duration and their impacts have to be examined individually.
5. Monetise all impacts: This step requires the analyst to attach monetary values to each of the impacts considered. However, this stage is difficult because there are numerous impacts which are hard to be quantified because they are not traded in market. Also, the nature of some impacts is abstract and therefore does not facilitate the quantification. The value is represented by the willingness of one to pay.
6. Discount benefits and costs to obtain present values: Regarding the projects that possess impacts that occur over years, there is a need to aggregate the costs and benefits that emerge in different periods. This can be implemented by discounting the future values of the impacts aiming to obtain the present values of the costs and benefits.
7. Compute the net present value of each alternative: The Net Present Value of each alternative is calculated by subtracting the Present Value of the costs by the Present Value of the Benefits. Particularly, the result is calculated with the use of the following equation; NPV = PV(B) – PV(C)
8. Perform sensitivity analysis: In procedures like CBA, there are always remarkable uncertainties. For example, the analyst cannot be totally certain about the predicted impacts as well as the monetary value assigned to them. Therefore, a sensitivity analysis can handle these uncertainties.
9. Make a recommendation: Generally, the analyst at the end of a CBA should make a recommendation which is most of the times the project with the largest NPV. However, it should be noted, that the sensitivity analysis can show that the alternative with the highest NPV is not always the best.

As already mentioned in the introductory part, another tool which is used to test the financial benefits of a specific investment option is the ROI. However, in cases where the impacts can have an intangible nature, the CBA is considered more suitable (Jones, 2006).

On the one hand, ROI is an accounting model which calculates the cash flows that are generated by a specific investment over time (Jones, 2006). Additionally, is considered one of the several possible ways to evaluate proposed investments because it compares the potential benefit or gain from an investment to how much it costs (Giel & Issa, 2013).

On the other hand, CBA is an economic model, that evaluates all kinds of costs and benefits that are caused by the proposed investment over time and produces a benefit-to-cost ratio (Jones, 2006). This ratio makes the whole evaluation more easily comprehensive for the reader.

This method is chosen because of its economic rationality and the monetary foundations that it provides. In addition, it helps the researcher monetise all the costs and benefits that exist in each project, and considers the qualitative aspects of it as well. In this way, she is able to eventually calculate the B/C ratio in any project and extrapolate useful conclusions based on it.

Moreover, this method is preferred to others existing because it involves thorough calculation of the positive and negative costs and, at the same time, considers the special conditions and characteristics of the project. Thus, the reader can simply understand what lies behind the substantiation and the sources that generate the numerical results.

3.2.2 CBA for BIM Implementation during Execution phase

The objective of this research is to develop an analytical method to substantiate the positive and negative costs of BIM implementation in AEC processes. The CBA differs from previous models in that it is based on empirical data recorded in real-life situations meaning construction projects (Lu, Fung, Peng, Liang, & Rowlinson, 2014). BIM implementation requires two processes: BIM work and site investigation for BIM implementation (Shin, Lee, & Kim, 2018). According to Fig. 10, the highest costs emerge during the implementation of this technology. Therefore, this phase is considered the one that should be further investigated.

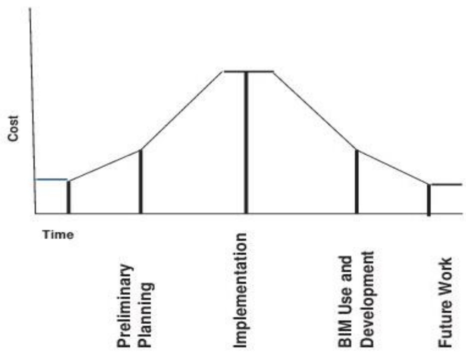

Figure 10 Cost of BIM implementation (Hardin, 2009)

In order to achieve so, actual ongoing or completed construction projects need to be examined thoroughly in order to conduct a CBA of BIM implementation. CBA which is based on economic rationality compares alternatives and makes choices based on monetary valuation (Hwang, 2016). Therefore, in this part, efforts are made in order to assign monetary values to the costs and benefits of BIM implementation in order to compare and evaluate the employment of BIM during the execution of a construction project. Hence, construction projects of BAM International of a Construct Only type of contract will be thoroughly studied.

3.3 CBA for BIM Implementation

Due to the recent introduction of BIM, its usage it is not always a clear decision. In some projects, BIM implementation constitutes a requirement from the client. Therefore, BIM Execution Plan is formed at the beginning of the project and the contractor and subcontractors should all work according to the milestones and deliverables set. In this case, the reward of the contractor for the employment of BIM is included in the contract value. Also, the client is responsible for acquired the essential software licenses and hardware to be used. As a result, the contractor is not responsible for covering these costs. In contrast, in some projects, the implementation of BIM relies on the mindset of the contractor. To be more precise, the contractor is responsible to decide whether or not they will use BIM applications for the execution of the specific construction project. This decision is taken considering the complexity and the location of the project as well as the available resources. In other words, the implementation of BIM constitutes an initiative of the contractor and he is responsible for covering the associated costs on his own.

In this case, the contractor should be able to substantiate clearly the benefit that they will gain after the employment of BIM. Thus, he will be able to evaluate its usage. In order to do so, the contractor should carry out a CBA including all the costs and profits that will emerge during the project execution if BIM applications are used. Undoubtedly, there are numerous variables and processes to be taken into consideration while conducting a CBA of this kind. Hence, a framework which would provide a transparent and standard procedure, able to compare the cost and benefits of BIM in any construction project is of high value.

3.3.1 Evaluation of Costs

The costs of BIM implementation refer to the amount of money required in order to use this means of creating and managing information in a construction project. Based on the interviews conducted, an effort was made to define these costs and assign the monetary value corresponding to them. Undoubtedly, each project involved different software, hardware and BIM team and consequently required different amount of resources. However, an attempt was made to find the common sources of cost among the projects and define categories for them. Hence, the 3 categories made based on the sources of BIM costs in construction projects are the following:

- Software: Based on the scope, size, location and the type of the contract of each project, different BIM execution was planned. As a result, the software to be used was chosen according the needs of the project and the requirements of the client. The costs that accompany the use of software refer to its acquisition, meaning the licenses that had to be bought in order to use it. It should be remarked, that in order to ensure interoperability, BAM International as a contractor, should use the same software as the architectural and structural designers. Consequently, the required licenses must be acquired. The cost of the software can be calculated as follows:

$$Cs = \sum_{i=1}^{n} Cli * Ti \qquad (1)$$

Where, C_S: the cost of software in €

C_{li}: the cost of license per software (i) per day in € and

T_i: number of days that software i is used

N: number of different software programs

- Hardware: Apart from the special software, the essential hardware has to be acquired as well, depending on the needs of the project. This hardware might not be already available by the company especially in projects located on places where BAM International has not operated before. Thus, the BIM execution on-site requires the usage of hardware such as computers, tablets, laser scans etc. The costs of this hardware is covered most of the times by the contractor. (C_H)
- Working hours: The use of software and hardware requires the essential amount of human resources either on-site or at the office. Usually, the contractor forms a BIM team which consists of the BIM Manager and a few technicians who possess the necessary knowledge. Hence, a monetary value is assigned to the working hours that the members of BIM team devote to the project. It should be noted that the value of a working hour depends on the location of the project, the local currency and the local cost per hour.

$$Cw = Wh * Ct \tag{2}$$

Where, Cw: the cost of working hours in €
Wh: the number of working manhours on BIM
Ct: local cost rate per working hour (€/hour)

To conclude, in each project, the costs will be analysed and assigned to the three categories aforementioned in order to clearly define the variables, technological means and processes considered.

3.3.2 Evaluation of Benefits

3D visualisation capabilities in combination with the time factor, turn BIM into a virtual construction platform. As a result, comparisons of the as-planned and as-built progress in BIM are possible at any time and can keep the project participants up-to-date on a variety of tacit issues, such as constructability reviews, safety checks and proactive schedule optimizations (Li, et al., 2014).

The benefits resulting from the implementation of BIM in a construction project vary and are hard to be clearly quantified. This is mainly caused because of the lack of information available. Also, there remains a lack of established quantitative knowledge regarding the impact that BIM can have on the general outcome of a construction project and how it can enhance it (Li, et al., 2014).

Tangible benefits

The term “tangible benefits” refers to the effects that are relatively easy to determine (Mouter, CBA) and, thus, can be quantifiable and associated with a monetary value. Therefore, all the tangible benefits if they are analysed in detail lead to the most important benefit of BIM; the saving of costs.

Cost saving: The saving of costs constitutes the main tangible benefit of BIM implementation. This benefit emerges from different sources that will be analysed. The gains that arise after the usage of BIM are the variable that will be compared to the total costs of BIM employment in order to evaluate its usage.

- Time saving (B_T): The applications of BIM such as the 3D model and 4D planning bring numerous benefits that result to saving of time. To be more precise, there is efficiency on time and the duration of an activity is reduced. It should be mentioned that the result of this benefit is the efficiency on time gained by the contractor. The contractor receives the 3D model from the designers and still has to work on them in order to create a 3D model of higher detail (LOD400) which would be ready to be built. To be more precise, BAM International as a contractor works on the 3D model for permanent works (LOD350) as well as the rebar modeling (LOD400). Eventually, they broadcast the models on BIM360 Glue and export 2D shop drawings to be used for Site Execution. It is proved that working on 3D model requires fewer working hours than working on 2D drawings (Hergunsel, 2011). This difference on time increases the efficiency of the contractor. Therefore, the costs of labour for the working people associated to this activity are reduced.

Especially, if an activity is on the critical path, the decrease of its duration affects directly the total duration of the project. However, it is assumed that if the activity is not on the critical path, the decrease of its duration does not affect the total duration of the project.
Each construction project involves running costs which include costs for administration, equipment and labour. Consequently, the saving of time leads to saving of running costs of the whole project. As a result, the tangible benefit which emerges from the use of BIM can be simply calculated considering the time, and consequently the cost, that the same procedure would take if it was executed with the traditional way.

- For non-critical activities

$$Bt = \Delta t * Cw = (Tt - Tn) * Cw \qquad (3)$$

- For critical activities

$$Bt = \Delta t * Cr = (Tt - Tn) * Cr \qquad (4)$$

Where, Bt: the tangible benefit of time saving in €
Tt: number of working hours with the traditional way
Tn: number of working hours with BIM usage
Cw: costs of human resources per working hour in €
Cr: running costs of the project per working hour in €

- Reduction of waste (B_M): 3D model increases the accuracy of Material Take-Off (MTO) and the Bill of Quantities (BOQ). If the 3D model is not used, the Project Team must estimate the quantities by hand. This procedure is associated with the risk of errors in calculations. Consequently, when quantities are estimated according to the 3D model, there is reduction or errors regarding the quantities of materials. In other words, the margin of errors regarding the BOQ is decreased. As a result, the over-ordering of materials is avoided and the waste of them at the end of the project is reduced. This benefit can be quantified by comparing the amount of materials if the calculations was executed with the traditional way to the amount of materials calculated with the implementation of BIM. Of course, this calculation should be done for each type of materials considering that their price varies.

$$Bm = \Delta Q * Cm = (Qt - Qn) * Cm \qquad (5)$$

Where, Bm: the tangible benefit of waste saving in €

Qt: the quantity of materials calculated with the traditional way (in m^3, m^2 or by piece)

Qn: the quantity of materials calculated with BIM usage (in m^3, m^2 or by piece)

Cm: the cost of material per m^3, m^2 or by piece in €

- Prevention of potential failures (B_F): BIM applications offers the ability to detect clashes, defficiencies and errors at an early stage. This helps the contractor face these conflicts before going to the construction site. As a result, failures and the associated cost to these failures are avoided. If these conflicts were not detected and solved on time, then the contractor would have to pay additional cost in order to solve the clash and pay the extra resources that would be needed in order to fix the problems. This benefit is defined by the additional amount of money that would be needed if the failure had actually happened during the project execution phase on the construction site.

Added value (B_V): In case BIM implementation is a requirement of the client, and therefore is included in the contract/BOQ, the cost to the client of the BOQ item is considered benefit for the contractor. This benefit consists of the additional value that the contractor gains because he is selling these services to the client. Therefore, this benefit is the amount of money presented in the BOQ, that the client pays and the contractor perceives.

Intangible Benefits

In contrast to tangible benefits, intangible benefits are the abstract and non-quantifiable effects, which are therefore difficult to concretely estimate both 'ex ante' and 'ex post' in a CBA. Regarding the implementation of BIM, there are currently numerous intangible benefits which in specific cases or events can be tangible. Therefore, this part refers to the benefits that are currently intangible but the framework aims to quantify them.

- Trust: The visualisation of 3D modeling and the clear arrangement of 4D planning give to the client and the numerous stakeholders a better understanding. Thus, they help the contractor gain the trust of the client and other stakeholders and also give confidence to all parties who take part in the construction.
- Supervision: BIM applications give to the Project Team the tools to supervise the process of the execution and monitor in detail. In this way, the time and cost limits are constantly considered and the human resources are controlled.
- Commercial use: Apart from the tangible benefits of commercial use, this aspect can also offer intanginble benefits. To be more precise, the possession of information and data regarding the project can give to the contractor many possibilities. Firstly, it establishes his position and contribution to the whole project. Secondly, the increased documentation helps in forming complete claims and thus, increase the possibility for these claims to be accepted by the client. In addition, during the execution, he can use this information he can track changes and specify which of the stakeholders should bare the cost of them. Finally, based on the available data he is able to verify the results at the end of the project.
- Quality: Up-to-date as-built drawings can be exported from the 3D model during the progress of the construction which can offer higher quality and more detail than the traditional 2D drawings. This enhancement of quality is caused because clashes and mistakes are detected on time and the information is taken from the source.

- Collaboration: The communication and collaboration among the stakeholders and within the project team is improved. The participants of the project work in a Common Data Environment which facilitates the distribution of information. As a result, the people working in the project can cooperate and exchange information smoothly.

3.4 Problems with the Quantification of Benefits

As already mentioned, despite the beneficial side of BIM, there are numerous barriers that hamper its usage. One of the main obstacles is the lack of an established quantitative knowledge as to how BIM can ameliorate the overall outcome of a construction project. To be more precise, the lack of clear substantiation of the costs and benefits does not encourage the employment of BIM in construction projects.

So far measuring tools have been designed in a way that requires BIM users to report the associated costs and benefits. On the one hand, these tools are useful in that they involve frontline BIM users and encourage them to examine costs and benefits comprehensively. However, the weakness of these tools is that they rely mainly on anecdotal evidence and the subjective judgments of users (Lu, Fung, Peng, Liang, & Rowlinson, 2014). As a result, potential users of BIM do not have a clear understanding of the expected costs and benefits. The causes and possible solutions of this problem are further analysed.

3.4.1 Causes

- Insufficient knowledge of a benchmark situation without BIM: Due to the recent introduction of BIM, in most of the times, the Project Team decides to implement BIM without investigating the alternative. In other words, stakeholders are not aware of the situation and the progress without the use of BIM. As a result, there is not available data to compare the benefits that emerge with and without BIM.
- More assumptions needed: The fact that the two alternatives are not considered leads to assumptions. To be more precise, in order to substantiate the benefits of BIM, the Project Team must make several assumptions regarding what would have happened if BIM had not been used.
- Benefits are not detected on time: In the majority of the projects, the benefits are not detected and recorded on time. Previous research has indicated that many asset owners do not prepare a benefits delivery plan when considering an investment in IS and are unable to determine if expected benefits are being achieved (Love, Simpson, Hill, & Standing, 2013). Consequently, when BIM implementation is investigated, the information needed is not taken from the source. As a result, when the benefits are substantiated, the Project Team has lost track of it and it is difficult to go back. Hence, most of the benefits are considered intangible and hard to be quantified.
- Relying on anecdotal testimonies does not capture the full picture: When the benefits are not detected on time, the Project Team has to rely on testimonies and interviews of people that worked on site. However, if this happens when the project has been completed, the benefits detected are more vague and intangible. In contrast, if these positive profits were recorded on the spot and according to specific events, then they would be associated to a real value more easily.
- Unreliable calculations: The assumptions that need to be done in order to quantify the benefits after the project is completed, lead to unreliable calculations. The accuracy of these calculations

depends on the crisis of the analyst and the assumptions that has to make in order to conclude to some monetary values.

3.4.2 Potential Solutions Proposed

- Keep a detailed record: A detailed daily or weekly record of the costs and benefits would capture accurately the positive and negative costs and avoid assumptions. This record could have the form of a journal or spreadsheet and would include thoroughly all the amounts of money either as inputs or outputs. Also, it would include specific events that caused the benefits. This record would constitute one of the responsibilities of the people working on the construction site and the member of the BIM team. Therefore, it would not require additional cost for the contractor.
- Conduct lessons learnt sessions: Another productive solution would be to hold sessions of lessons learnt every month as a group in order to capture these lessons from other stakeholders and third parties regarding BIM. These lessons would help improve the performance and also focus on the inputs from the benefits. In addition, it would encourage the group to keep up to date with the changes in the project and the technological means available and adjust to them if possible.

3.5 Framework

3.5.1 Functionality of the Framework

The aim of this framework is to provide a defined procedure that will achieve the quantification of costs and benefits due to BIM implementation. This will be attained by thoroughly analysing the source of each cost and benefit and assign monetary values to it. In this way, even the intangible benefits can receive a value and thus constitute a variable in the formula. The most underlying aspect of BIM evaluation is to understand what is to be measured. The dynamic nature of BIM methods means that its content will regularly change. Consequently, qualitative measures that provide a rationale for plenty of intangible benefits are required (Love, Simpson, Hill, & Standing, 2013).

The framework to be developed will constitute a standard method, applicable in any construction project. To be more precise, it would be the stepping stone between the problems and the solutions mentioned above. Currently, the most important obstacle of the quantification of benefits is their abstract nature. Therefore, this framework would be the bridge between the intangible and tangible benefits as it would make them as much quantifiable as possible.

In this way, the user would have a useful measurement tool for BIM implementation. Some of the most used methods employed for prediction and evaluation by asset owners are the Internal Rate of Return (IRR), Net Present Value (NPV) and ROI. The foundation of such methods is that the costs of an investment need to be related to the benefits that it aims to bring. However, a challenge with this balancing act is that costs normally arise immediately, while the benefits incure later in the future (Love, Simpson, Hill, & Standing, 2013).

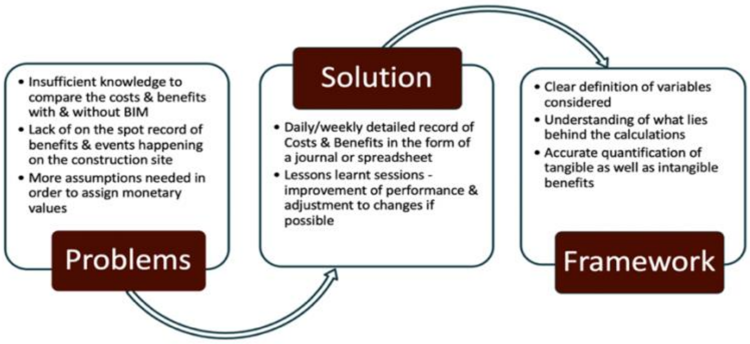

Figure 11 Functionality of the Framework

3.5.2 Formula of the Framework

Benefits Characterisation

The framework is developed on Ms-Excel and acquires the form of an inclusive and detailed table. This table includes all the steps that the user should follow in order to reach the calculation of Costs and Benefits ratio. It should be mentioned, that these steps represent the CBA guidelines and are applicable in any construction project. In this part, a detailed description of the framework is given in order to explain the way it works and familiarise him with the functionality of it.

Firstly, the framework involves an extensive list including all the benefits that emerge from the implementation of the different aspects of BIM. Particularly, the 3D model and 4D planning are only considered as the 5D linkage with cost has not been widely used in the AEC industry yet. Subsequently, 8 different workflows of BIM are chosen to be analysed including the following;

1. 3D permanent model
2. 3D model for Quantity take-off
3. 3D Based surveying
4. 4D model for planning
5. 4D progress monitoring
6. 5D model for cost estimating
7. Site data capturing
8. Added value

Following the initial categorisation, for each workflow, there is a short list of the main benefits that are generated along with a brief definition of it. These benefits are chosen based on the investigation of the Case Studies that was carried out. The data collection in combination with the interviews with people that possess expertise and experience in the AEC industry, led to the identification of the most valuable benefits. Subsequently, the user has to define if each benefit was acquired in the project under investigation.

As expected, the benefits listed are either quantifiable or non-quantifiable; based on the information that is available. Thus, the first step after the definition is the characterisation of them as tangible or intangible. It should be remarked, that this characterisation concerns the specific project which is studied. To be more precise, as already mentioned, abstract benefits that are considered intangible, can be quantified if the right data, regarding the on-site conditions, is available. Therefore, the definition as either tangible or intangible depends completely on the information that the user of the framework possesses.

Consequently, the use of the framework continues as follows. If the benefit is classified as intangible, the substantiation of it stops there. In contrast, if the user classifies it as tangible it means that he has the right information in order to assign to the profit a monetary value. Therefore, he has to define the factor upon which the quantification will be achieved. These three factors were analysed in section 3.5.2 and involve; (1) Saving of time, (2) Reduction of waste; (3) Added value in the contract. These three factors represent different ways that can lead to cost saving for the side of the contractor. Then, for each category the user has to give the essential data as follows.

- **Saving of time:** The user is required to insert the duration of the task with and without the implementation of BIM. **T**he actual duration that was achieved after the BIM implementation, is readily available on the reports of the project. On the other hand, the estimation of the duration of the task without BIM requires an assumption by the users. This assumption can be supported by data found in the published literature. However, it constitutes one of the flaws that characterise the existing evaluation methods. Hence, it is suggested that the user makes a conservative assumption and do**es** not overestimate the possibilities of BIM. Subsequently, the user has to multipl**y** the amount of time that was saved with the operational costs. The operational cost signifies the running cost that the contractor has to cover for every day spent on the construction site. The result is the amount of money gained by the contractor.
- **Reduction of waste:** If the user claims that the cost saving was achieved because of reduction of waste of materials, then the quantities of materials with and without the use of BIM should be inserted in the formula. The comparison refers to the BOQ calculated based on the 3D model and the BOQ that would have been formed with the traditional way. Similarly to the previous factor, subjective judgements have to be made because the actual events were not recorded the moment they happened on-site. As a result, the user cannot estimate accurately the quantity of materials that were leftover at the end of the project. In any case, the user is required to insert the quantity and the corresponding price in € for each m3, m2 or unit. The value which emerges is the benefit gained by the contractor because of waste reduction.
- **Added value:** The third factor refers to the value that BIM implementation adds to the reward of the contractor. As already mentioned, if BIM strategy constitutes a requirement from the side of the client, then the reward of the contractor in the contract might be higher. This value is a clear number and refers to the part of the contract value that corresponds to BIM execution.

Literature Reference

The monetary quantification of costs and benefits is based on the information and data acquired from the interviews and the reports of the company. However, the detailed literature review helped in collecting valuable data regarding this quantification as well. Hence, a reference on the data provided by the already published literature is made. This reference is essential in order to support the calculations and confirm their soundness.

Cost Definition

This part constitutes the less time-consuming step of the framework as it requires data which is surely recorded. Before the calculation of the final B/C ratio, the user is requested to insert carefully the costs that were required for the implementation of BIM applications. Given that the nature of costs could be either direct or indirect, the evaluation framework takes into account only the direct costs. This choice can be explained because these costs are considered to be essential for the usage of BIM, otherwise without them the implementation would be impossible. For example, the cost of training is not considered as it constitutes a cost that will be partly absorbed by the company in future projects. Hence, the costs of software, hardware and personnel are considered direct and have to be inserted from the user. Finally, the total cost is calculated.

Costs

Software: Price per license (€)

C_S = Sum of licenses cost (€)

Hardware: Price for new hardware acquired (€)

C_H = Sum of hardware that is purchased (€)

Personnel: Number of working hours x price per hour (€)

C_W = Number of resources x number of days x number of working hours x price per hour (€)

Total Cost = $C = C_S + C_H + C_W$ (6)

Benefits

Cost saving: $B_C = B_T + B_M + B_F$(€) (7)

Added value: B_V (€)

Total Benefit = $B = B_C + B_V$ (€) (8)

Cost and Benefit Ratio

The result of a CBA is the Cost and Benefit Ratio ($\frac{B}{C}$). This value reflects the amount of money gained for every unit of money invested. However, the function of the framework is not limited in simply assigning monetary values to the costs and profits of BIM. In contrast, the aim of this process is to familiarise the user with the actual value that the benefits offer to the side of the contractor. This is achieved by clearly presenting the variables that lie behind the calculation of costs and profits. In this way, users are able to evaluate how BIM applications work and if they are finally beneficial or not.

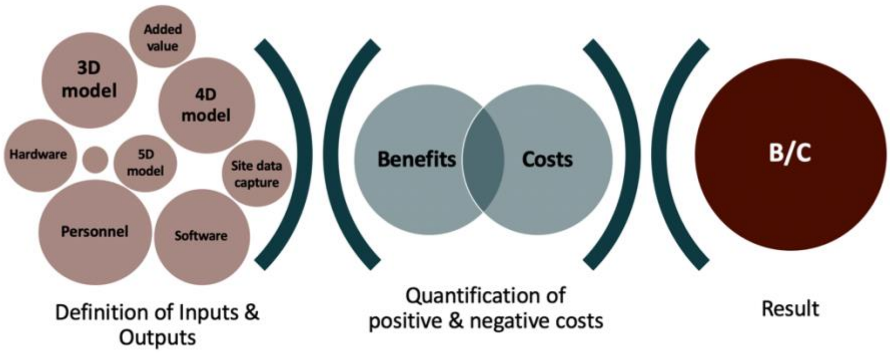

Figure 12 Visual representation of the Framework

3.6 Conclusion

This chapter focuses on the challenges around the quantification of costs and benefits associated to the implementation of BIM. The aim of the suggested Framework is to face these problems by

Sub-question 3: *How can the costs and benefits associated to the implementation of BIM be effectively substantiated?*

providing efficient solutions. In this part, the researcher makes an introduction to the CBA which constitutes the foundation of the suggested evaluative method. Moreover, she explains in detail the way that the evaluation will be executed and provides a thorough description of the functionality of the Framework. After completing the above, the researcher is able to answer the Sub-question 3.

The effective substantiation of costs and benefits is proven quite challenging. The most important problem is the lack of sufficient knowledge and information regarding BIM implementation. This lack requires personal assumptions and testimonies regarding the costs and benefits of BIM. Subsequently, this leads to inaccurate calculations.

This substantiation can be effectively implemented and consists of a few steps. These steps involve the detailed record on a regular basis of important data and all the events that happen on site and have to do with BIM. These events would be caused due to BIM usage and would either reduce the duration of the activities, reduce the waste or would offer added value to the services. The reduction of the duration and waste is directly connected with saving of cost. Therefore, the benefits would be assigned a specific monetary value with the use of Eq. (3), (4), (5) & (7). Eventually, the Total Benefit of BIM is calculated according to Eq. (8).

Apart from the benefits, the Project Team would be responsible to thoroughly record all the required costs which involve the cost of software, hardware and personnel that are needed specifically for the usage of BIM. The cost of software would be quantified based on the cost of the licenses needed with the use of Eq. (1). Following, the cost of hardware refers to the amount of money required in order to acquire the technological means that would support BIM implementation. Finally, the cost of personnel corresponds to the salary of the people that work specifically on BIM methods and is calculated according to Eq. (2). Finally, the Total Cost of BIM stems from substantiation of costs and benefits associated to BIM is the B/C ratio which emerges by dividing Eq. (8) by Eq. (6).

The proposed Framework deals with the challenges in substantiation as it provides standard guidelines which aim to record all the important data, facilitate the calculation of costs and benefits and avoid personal assumptions.

4. APPLICATION OF THE FRAMEWORK ON CASE STUDIES

4.1 Introduction

As already mentioned, BAM International intends to fully adapt BIM tools in order to add value to the services it provides. This procedure should be carefully planned according to the needs of the clients and the company as well. The aim of the proposed Framework is to capture the particular characteristics of each project through a standard method which is applicable in any project. In this way, the contractor can be fully aware of the monetary value of BIM implementation according to the special conditions of the project and the requirements of the client.

Considering that each construction project requires tailor-made management, the proposed evaluation procedure is applied on 5 different Case Studies. The Cases Studies that will be explored are listed on Table 1. Each Case Study possesses different characteristics. These characteristics involve the workflows of BIM used, the Total Cost and the type of the project, the costs of BIM implementation required as well as the size of it. The Table 1 includes information such as the location of the project, the total cost of it, the workflows of BIM that are used and the one that ensured the highest benefit. In order to introduce the reader to the projects. Moreover, as mentioned before, they also refer to the conditions of the project such as the location of the project itself, the working location of the BIM team and the requirements of the client regarding BIM applications. Hence, in order to extrapolate accurate results regarding the B/C ratio in each Case Study, all the above characteristics are thoroughly defined.

The application of the proposed standard and transparent method on Case Studies aims to provide a full insight into the employment of it on real-life situations. This application will be achieved through face-to-face interviews which will allow the researcher collect the data she needs. The result of the application will be the interpretation of the B/C ratios and will provide a holistic approach regarding the evaluation of BIM implementation in construction projects.

Table 1 Main characteristics of Projects

Project	Location	Total Cost of the Project	Type of Project	Workflows Applied	Workflow of the Highest Benefit
APM Terminal	Costa Rica	$ 500.000.000,00	Marine	3D Permanent Model, 3D Model for QTO, 3D Based Surveying, 4D Model for Planning, 4D Model for Progress Monitoring	4D Planning
London City Airport (LCA)	UK	€ 95.000.000,00	Building	3D Permanent Model, 3D Model for QTO, 4D Model for Planning, 4D Model for Progress Monitoring, 5D Model for Cost Estimation, Site Data Capturing	3D Permanent Model
Musem of the Future	UAE	€ 204.229.663,11	Building	3D Permanent Model, 3D Model for QTO, 3D Based Surveying, 4D Model for Planning, 4D Model for Progress Monitoring, 5D Model for Cost Estimation, Site Data Capturing	3D Permanent Model
IKEA Project	Indonesia	€ 40.000.000,00	Building	3D Permanent Model, 3D Model for QTO	3D Permanent Model
BAS	Antarctica	£ 28.783.627,00	Building	3D Permanent Model, 3D Model for QTO, 4D Model for Planning, 4D Model for Progress Monitoring, 5D Model for Cost Estimation, Site Data Capturing	4D Planning

4.2 APM Container Terminal in Moín - Costa Rica

4.2.1 General Information

This project involves the construction of a new container terminal for APM terminals in Moín, Costa Rica as shown on Fig. 13. The type of the contract between the client and the contractors was

Construct only. The clients were the Government of Costa Rica and APM terminals; an international container terminal operating company. The contractor was a consortium including BAM International and Van Oord, two Dutch construction companies. It should be remarked that each company had different scope and role in the whole project. The design of the electrical work package was subcontracted to an electrical design company (ABB).

The initiation of the project was on October 2013 but it was not until the beginning of 2015 that the execution actually began. This delay was mostly due to environmental and permit reasons. In addition, the initial duration of the project implementation was 32.5 months. However, because of the complexity of the project and several other reasons, the container terminal was handed over to the client on the 1st of March 2019. This delay was foreseen and accepted by the client and was caused by numerous reasons. Firstly, a significant reason of the delay were the weather conditions and specifically the extraordinary height of the waves which was not expected. Particularly, given the special location of the project, a temporary protection was built based on certain wave data. However, these values were exceeded as the wave conditions were harder than anticipated. In addition, delays were caused by changes in the design from the designers and the client.

The usage of BIM applications was an initiative from the side of the contractor and was not imposed by the client. It was not before 2015 that contractor realised that DC would be beneficial. Indeed, at the end of the project the contractor much more than expected. Given the remote location of the project, a BIM team of 5 people including the BIM Engineer worked on site and, when the project was completed, this choice was considered of high importance because they managed to apply BIM efficiently. Particularly, they made use of multiple aspects of the 3D Model (3D Permanent Model, 3D for QTO and 3D Based Surveying) and the 4D Model (4D Model for Planning and 4D Progress Monitoring). Eventually, gained the highest benefit from the Coordination of interfaces and simultaneous operations, which was facilitated with the use of the 4D Model. Both workflows accommodated commercial purposes as the contractor was able to explain the time delays they faced to the client. This ensured credibility between the two parties. Following, the substantiation of the costs and benefits was implemented on the Framework and is given on section 4.2.2.

Figure 13 APM Terminal in Moín, Costa Rica (BAM International Projects, 2020)

4.2.2 Definition & Quantification of inputs & outputs

According to the Fig. 14 and Appendix A, the costs of BIM mainly involved the cost of software, hardware and personnel while the tangible benefits refer to the as-built drawings, the surveying and the progress monitoring.

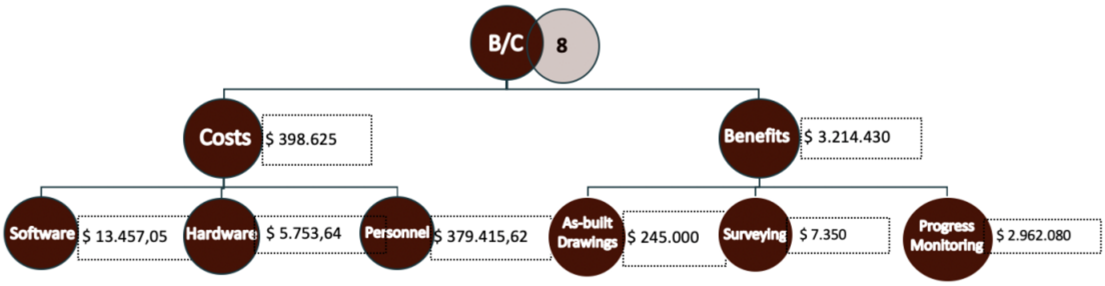

Figure 14 Quantification of Costs and Benefits in APM Terminal

Inputs

- Software

In order to implement the applications of BIM the company had to acquire the special software which was not already available. This software was mainly required for the 3D modeling and the 4D planning. Particularly, there was a requirement for software from Autodesk and Synchro Pro. The cost of the software refers to the number of licenses that have to be bought for the necessary period of time. Hence, most of the times the cost is quantified on a daily basis.

- Hardware

It should be remarked that BIM was used by a team on-site. Therefore, the essential hardware had to be bought by the company. This included mainly computers and tablets.

- Personnel

The BIM team consisted of 5 people (Draftsmen, BIM Modeler & BIM Engineer) working on site and on different aspects of BIM. The cost of human resources is estimated by multiplying the number of resources with the local cost per working hour.

Total cost = $ 398,625

Outputs

The tangible benefits represent the ones that can be substantiated. Their quantification is achieved based on the period of time which was saved in each activity after the implementation of BIM. Therefore, in order to estimate the saving of time the duration of the activity with and without BIM is given. The lack of on-the-spot information though, requires assumptions regarding these durations. Then, the difference of these two durations is calculated and the result corresponds to the saving of time because of BIM usage. This period of time is multiplied with the number of resources that are involved in this activity and with the monthly rate of the resources in dollars. The result is the benefit gained by the specific activity. Considering that the rate of the resources is monthly, every duration is estimated on a monthly base. Precisely, for the APM Terminal, the following calculations emerge:

- As-built drawings

Considering that the 3D model was updated during the construction of the terminal, at the end of the project, the team had available all the As-built drawings. This helped them save time and ensure accurate and up-to-date drawings of the whole project. If the 3D model had not been used, at the end of the project, 2 draftsmen would be needed to work further in order to produce the 2D as-built drawings and illustrate in detail the final product. After the implementation of BIM, the duration of time needed for the extraction of as-built drawings was 0 days. As mentioned above, the as-built drawings are extracted from the 3D model when the execution phase is completed. Therefore, no additional time to work on their production is needed whereas if BIM was not used, the production of 2D as-built drawings would take 5 months. Also, 7 crews of 2 working people would be needed. This is multiplied with the monthly rate in dollars.

- 3D Based Surveying

Due to the use of the 3D model, the surveying on site was facilitated and much time was saved. At the beginning, the surveyors would go to the construction site and define the coordinates manually with the total station. Instead, with the use of BIM, the surveyors could install the 3D model and thus have the coordinates already available in their total station. Apart from saving time on daily basis, it also ensured accuracy in the coordination. The use of 3D model facilitated significantly the work of surveyors. Particularly, the surveyors could install the 3D model on their total stations and thus, have the coordinates of the construction site available. As a result, they saved 1.5 hrs per day in order to capture all the elevations and the coordinates needed. Again, this duration that corresponds to the saving of time was multiplied by the number of crews needed and the monthly rate of each crew.

- Interface coordination

4D model was efficiently used for time planning during project execution. Hence, it was remarked that the average progress had an increase from 1.08% (without BIM implementation) to a 1.82% (with BIM implementation). As a result, there was a 68% saving of time. In short, this means that if an activity lasted 1 day with the use of BIM, it would last 1.68 days without it. Therefore, there was 8% quicker progress. Regarding the coordination of utilities, it emerges that this activity lasted 6 weeks with the use of BIM and 10.08 without it. The saving of time led to saving of operational costs. Thus, the difference of the two durations is multiplied with the operational costs of the project per day. The construction of APM Terminal in Moín was a large project with a size of 40 hectares. Also, it was a significantly complex project involving numerous different disciplines and activities. Consequently, there was high need of efficient interface management. Particularly, the multiple activities had to be coordinated carefully. Otherwise, there would be confusion on-site and conflicts among the different tasks which would lead to unforeseen time delays. The coordination of interfaces was achieved with the employment of 4D planning.

Additional Information: The price of the human resources in dollars is given on a monthly rate. Hence, the saving of time is also calculated on a monthly basis. In all the calculations the following data is used:

- 1 week includes 6 working days
- 1 working day includes 10 working hours
- 1 month consists on average of 4.33 weeks

The **Total Benefit** that emerges from the above calculations is **$ 3.214.430.**

Cost-Benefit Ratio

After the calculation of the costs and benefits of BIM implementation, their ratio is estimated. The result of this calculation is:

$$\frac{B}{C} = 8{,}063 \approx 8$$

4.3 London City Airport – United Kingdom

4.3.1 General Information

This project involves a contract for BAM Nuttall and BAM International for a concrete deck extension of 75.000 m^2 in London City Airport. The location of the project is shown on Fig. 15. The two companies formed a Joint Venture and were handed over the project by a Group of Investors. The motivation for this project was the problem of capacity in the airport. This problem led to increase of the traffic. The old airport was built 100 years ago and there were limitations. Particularly, there was only one runway and there was no taxi way. In addition, the main purpose of the extension was that there were a few parking spots for airplanes. The extension will also include a new terminal building. The deck is the first stage of construction, as part of the £480m City Airport Development Program. This program will significantly change London City Airport (LCA), aiming to offer improved facilities to customers, an expanded number of flights and more space to accommodate passengers. This expansion will enable annual passengers to grow from the current 4.5 million to 6.5 million. The piling and decking contract value is approximately €95 million (£85 million). The works on site were initiated in Spring of 2018 and the completion of them was scheduled for the beginning of 2020.

On this project, BIM Implementation was mandatory for the contractor. However, it was proven beneficial as it promoted collaboration, avoided delays and detected a significant number of clashes. The team used to have collaboration issues because the involvement of many participants and different subcontractors made the engagement to the project hard. The BIM workflows that were applied on this project involved the 3D and 4D model. The quantification of the benefits that were generated and the involved costs was implemented on the Framework and is given on section 4.3.2. When the project was completed, the engineers stated that, generally, BIM Implementation needs adequate training and sufficient resources which involve early to the process, in order to work. Eventually, they highlighted the potential they see in commercial use of BIM.

Figure 15 London City Airport in UK (BAM International Projects, 2020)

4.3.2 Definition & Quantification of inputs & outputs

Regarding the project in LCA, after the initial discussion with the Engineering Manager and the BIM Designer it was possible to collect some general data about the project and also identify the benefits that existed according to the list of the Framework. Therefore, during the following interactions with the Engineering Manager of the project, the quantification of the tangible benefits was achieved. Also, the data for the calculation of the costs of BIM implementation was collected. As a result, the following inputs and outputs of Fig. 16 were calculated. The calculations are given in detail on Appendix B.

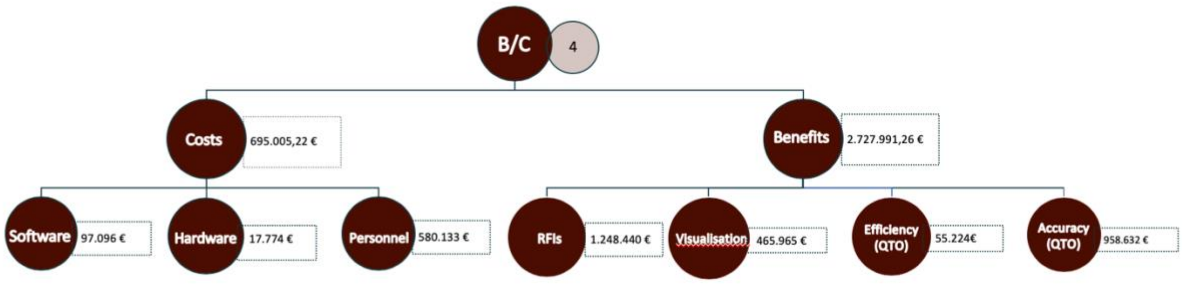

Figure 16 Quantification of Costs and Benefits in LCA

Inputs

As inputs were considered the cost of Software, Hardware and Human Resources that were required for the implementation of BIM applications. Particularly, regarding the Hardware, there were 8 computers acquired specifically for the usage of BIM. Also, there was required a smart screen and a pair of VR goggles. Following, there were required the licenses for the usage of the essential software. Firstly, BIM 360 & Revit provided from Autodesk were used for the creation and handling of the 3D model. Moreover, Revizto and Solibri were used for the integration of the multiple disciplines into the 3D model and the handling of the information. Hence, effective collaboration was achieved. Finally, Navisworks was used for the creation of the 4D Model. Finally, regarding the personnel, the BIM team consisted of the BIM Manager, the Project Information Manager, the Digital Designer, the Engineering Manager, the Document Controller, the 4D Planner and 5 Engineers. It should be mentioned that not all of the members were working constantly and only on the specific project. Therefore, a coefficient was considered in order to estimate the part of the total time period that was dedicated for LCA.

Subsequently, the **Total Cost** of BIM implementation for LCA were equal to **695.005,22 €**.

Outputs

- Requests for Information

The usage of the necessary software helped the BIM team rise Requests for Information on time. These requests helped a lot in solving the matters the emerged faster. These issues mostly concerned the design of the construction project. Therefore, BIM applications contributed in solving these RFIs in less days than it would normally take. In LCA, 550 RFIs were totally risen. The Engineering Manager claimed that 23 of those were BIM related. Hence, the solving of each of them would normally take 37,6 days. However, BIM applications helped solve them on average within 14 days. As a result, 23,6 days was saved from the solving of each RFI. This leads to a total saving of 542,8 days. Moreover, based on a conservative assumption that 5% of the activities relevant to RFIs are on the critical path, leads to a saving of 27,14 days of the total duration. Subsequently, this time saving is then multiplied with the operational cost per day and leads to a cost saving of **1.248.440€**.

- Efficiency of Processes (Time)

The 3D model contributed in creating the BOQ in an efficient and less time-consuming way. According to the Risks & Opportunities Register, the contract is Lump Sum including the BOQ. However, this type of contract involves the risk of estimating incorrect quantities. If the 3D model had not been used for the QTO, the contracting company, in order to deal with this risk, would have to add more time and resources in the creation of an accurate BOQ. Therefore, the time and cost that was saved from this procedure, is considered a benefit for the contractor. Particularly, based on estimations, without the

3D model, 3 Engineers would be needed. Each Engineer would do 3 full revisions; each revision would last 3 weeks and would cost 1.534€. In total, this generates a profit of **55.224€**.

- Accuracy of Estimate

The Risks & Opportunities Register also includes the risk of "Quality or dimensional problems with placing precast units in P1". The strategy to deal with this risk would be to carry out on-site checks prior to planning. This would require additional time and resources accompanied with the necessary cost. These resources would be responsible for measuring the as-built and receive the new PC elements. This could also, possibly lead to standby-time. Therefore, the handling of this risk would require 2 Engineers in order to carry out 1 full revision of 12 weeks. This cost, in combination with the additional cost of the PC elements and the standby time would lead to a cost of 958.632€. Considering that because of BIM implementation this cost is avoided, this amount is a benefit for the contractor.

Additional Information: For the calculations realised above, the following statements were considered.

- 1 month consists on average of 4.29 weeks
- 1 month consists of 22 working days
- 1 week includes 6 working days
- 1 working day consists of 10 working hours
- 1 £ ≈ 1,18 €

Considering all the above, the **Total Benefit** of BIM implementation for LCA is **2.727.991,26 €**.

Cost-Benefit Ratio

After the calculation of the costs and benefits of BIM implementation, their ratio is estimated. The result of this calculation is:

$$\frac{B}{C} = 3{,}925 \approx 4$$

4.4 The Museum of The Future in Dubai – United Arab Emirates

4.4.1 General Information

The Museum of the Future in Dubai is a project initiated by the Prime Minister of United Arab Emirates and aims to explore the future of science, technology and innovation. It is located close to Burj Khalifa and was expected to be hosting the World Expo 2020 starting the October of 2020. In contrast to its name, this building is mainly an exhibition space which will host innovative concepts. Also, it will include several spaces involving labs, foods and beverages as well as an auditorium of 400 seats. The Museum of the Future is significantly well-known on a worldwide level because of its unique and innovative design as shown on Fig. 17. This design also makes it a demanding construction project.
The type of the contract for BAM International was Construct only. However, it should be mentioned that the company was also responsible for the design of few elements of the project. The project was initiated on the 8th of January in 2017 and it is still under construction. It has not yet been handed over due to some delays. These delays are mostly caused by changes in the design and the complexity of the project itself.

Regarding the implementation of BIM on this specific project, experts claim that the execution of it would not have been feasible without the use of BIM applications. It should be remarked though, that the employment of BIM was a requirement from the client so the company already made use of it from the Tender phase. BAM International together with the Employer's Representantive, Employer Financial Consultant and the Subcontractors, held a BIM Kick-off Meeting in order to agree on the deliverables and the milestones. The most important result of this meeting was the BIM Execution Plan. Part of this meeting was also the definition of the BIM software and tools to be used by the team. The workflows of BIM that were applied on this project include the different functions of the 3D Permanent Model (QTO, 3D based surveying), the 4D Model (Planning and Monitoring), the 5D Model for Cost Estimation as well as the Site Data Capturing because a Laser Scan was used on-site. The clear quantification of the costs and benefits that was implemented with the use of the Framework, is given on the following section.

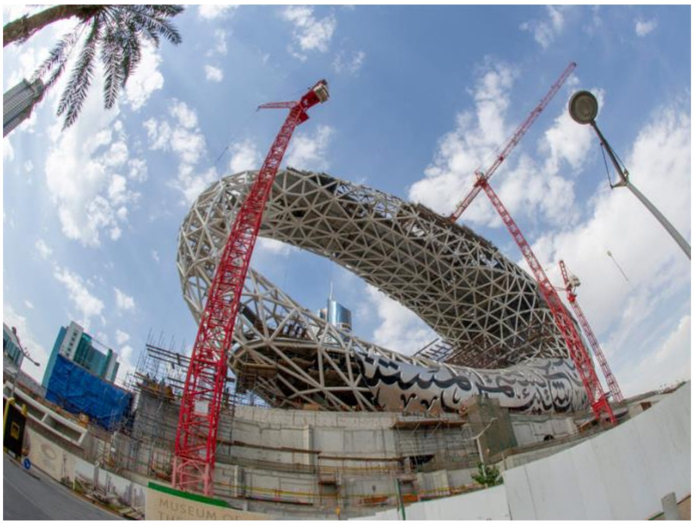

Figure 17 Museum of The Future in Dubai, UAE (BAM International Projects, 2020)

4.4.2 Definition & Quantification of inputs & outputs

According to Fig. 18, the costs of BIM implementation in the specific project mainly involve the cost of software, hardware and personnel while the benefits vary. The values that emerge for the costs and benefits are thoroughly presented on Appendix C.

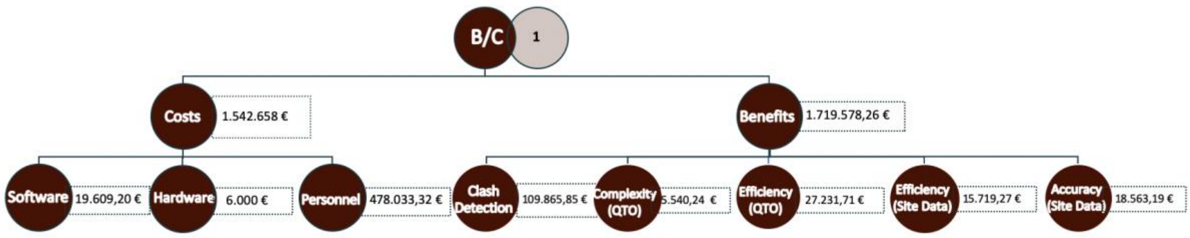

Figure 18 Quantification of Costs and Benefits in MotF

Inputs

- Software

During the Kick-off Meeting, it was decided that an Autodesk Package would be used including Revit, AutoCAD, BIM 360 FIELD and BIM 360 GLUE and Navisworks. Also, TEKLA Trimble and CATIA were used for the structural design and SYNCHRO for the planning of the project. The licenses of these software programs are one of the main sources of costs regarding BIM. However, in this case, most of these licenses were acquired by subcontractors or by BAM International during the Tender phase.

Therefore, BAM International was required to cover the costs of the working hours on BIM during the Execution phase. BAM International had to cover the costs of 5 licenses for REVIT 2017 and BIM 360.

- Hardware

The cost of hardware for the specific project involves the acquisition of work stations able to support the use of the aforementioned software.

- Personnel

The composition of BIM team was not the same during the whole execution of the project. The first 23 months, the BIM team consisted of 2 Structural Modellers, 2 Architectural Modellers, 1 MEP Modeller, 1 BIM Coordinator and 1 BIM Manager. However, the next 17 months the needs of the project changed so there was only 1 Structural and 1 Architectural Modeller. Hence, the BIM team included 5 members. It should be mentioned that considering that training was only done in-house, the training hours are considered part of the total number of working man-hours.

Outputs

- Clash Detection & Design Changes

The early detection of clashes among the Structural, Architectural and MEP drawings contributed in saving valuable time and cost later during the project execution. Particularly, a total of 88 clash reports were raised. Each of these reports helped save approximately 5 days in a later stage. Moreover, 379 coordination issues were raised. The solving of these issues led to a saving of 1 day for every clash solved. Eventually, in order to calculate the cost saving of this benefit, it was considered that 5 human resources were required that worked for 10 hours per day. The on-time dealing with these detected clashes and the coordination issues produced a profit of **109.865,85 €**.

- Complexity of Structure (Shape)

The specific building is very well known for its special and complex design. It is made of numerous steel diagrids. The structural diagrid was produced and imported in Revit. Considering that each diagrid is accompanied by its own type and ID, it was less time-consuming for the subcontractor to extract the quantities with the use of the 3D model. Thus, this feature was a huge cost-saver as it enabled the order the quantities in bolk and on-time. This QTO helped the contractor save 6 days. It should be mentioned that 2 people working 10 hours per day were required for the specific activity. Eventually, the benefit that was generated was equal to **5.540,24 €**.

- Efficiency of processes (Time)

The landscape of the Museum of the Future consists of a mount on which the building is located. Also, the landscape consists of plants, trees etc. The quantities of these parts would be hard to quantify without BIM, given that the shape of the mount is more abstract and the slope is very steep. Thus, with the usage of BIM, it was possible to select the surface and quantify the quantities. Moreover, architects made a lot of changes during the execution of the project which would also affect the surface area. These changes were easier to implemente with the usage of the 3D Model.

Similar to the landscape, the lobby shell of the building owns a special shape. The 3D Model enabled the technicians to quantify faster the calligraphy lights that would be placed on the outside of the lobby shell. These quantities were generated by the polylines used on the 3D model. Hence, this led to a time saving of 5 days which involved 2 people working for 10 hours as well as a more accurate BOQ.

In addition to the parts mentioned above, the 3D Model contributed significantly in the calculation of the materials needed for the façade and façade lighting. Considering that the shape of the whole structure was complex, according to the engineers it would be impossible to calculate the amount of the materials needed manually. Taking into account the time that was saved from the implementation of all the tasks analysed above, the cost that was eventually saved was equal to **27.231,71 €**.

- Efficiency of Data Collection and Handover

Apart from the intangible value, 3D Laser Scanning offered multiple tangible benefits to the contractors. To be more precise, this technology enabled the engineers verify the structure and save remarkable amount of time. For instance, engineers used the laser scan on the construction site in order to inspect the rebar of the corballs before the concrete was poured. The scan showed that the rebar was bigger than it should. Consequently, they were able to identify and solve the error on time before the pouring of the concrete began. Thus, they achieved a saving of the manhours and the cost that would be needed in order to fix the error in a later phase. The BIM applications helped the contractor save an amount of **15.719,27 €**.

- Accuracy of the Result

The site data capturing aims at capturing the actual situation on the construction site with the use of special equipment. Subsequently, this contributes in achieving the desired result within the level of tolerance initially decided. Also, when this procedure is done with the employment of the latest technological means, much time and cost are saved. Particularly, regarding the MotF, an RTC operator was used in order to mark the spots for the supports for the MEP services. If this procedure was done in the traditional way, the total station should be set on-site, the mark the spots and drill the holes for the hangers. This would ensure 4 hangers per hour. However, with the use of the necessary technological means, 52 hangers were spotted per hour. In addition, less supervision was required. This procedure generated a cost saving equal to **18.563,19 €**.

To conclude, the **Total Benefit** that is generated for the side of the contractor from the benefits quantified above is **176.920,26 €.**

Additional Information: For the calculations realised above, the following statements were considered.

- 1 working day consists of 10 working hours
- The local rate per hour of a technician is 11 DH.
- The local rate per hour of an Engineer is 77 DH.
- 1 DH ≈ 4,1 €

Cost-Benefit Ratio

After the calculation of the costs and benefits, their ratio is estimated. It should be highlighted that this was a BIM mandated project. Therefore, the cost of BIM applications alongside with the cost of personnel was covered by the client. As a result, in order to calculate the B/C ratio, the total cost is added to the benefit of the contractor. Thus, the benefit emerges equal to 1.719.578,26 €. The result of this calculation is:

$$\frac{B}{C} = 1{,}114 \approx 1$$

4.5 IKEA Project – Jakarta, Indonesia

4.5.1 General Information

This project involves the construction of a store of one of the most well-known brands on a worldwide level; IKEA. The type of the contract is Construct Only and BAM International is responsible for the delivery of this project to PT Archipelago Property Development; a subsidiary of The Dairy Farm International Group. The value of this project is approximately 40.000.000€. BAM International initiated the construction works on May 2019 and the completion of them is expected around September 2020. The building will consist of five floors which consequently include two basements and three retails floors. The large size of construction site is shown on Fig. 19 and the building, in total, will be composed of more than 90.000 m^2. This furniture and home products department store will become the second Indonesian IKEA store and will be located in the Jakarta Garden City area in the Eastern part of Jakarta.

Regarding the IKEA Project, BIM Implementation was a complete initiative of the contractor as the client preferred the old-fashioned management and had to be convinced about BIM benefits. The engineers and the Project Manager stated that the most important benefits were the reduction and avoidance of errors, the management of change on the drawings between the contractor and the subcontractors, the visualisation which ensured the understanding and the satisfaction of the client and the saving of time due to the early identification of risks and problems. It should be remarked, that on this project, only the 3D Model and its aspects (QTO) have been employed and the costs and benefits associated are calculated in detail on the Framework and are presented on section 4.5.2. Nevertheless, the engineers based on the experience they gained after this project, they believe that there is a good future ahead in digital documentation and the engagement from the start in this procedure is the key.

Figure 19 IKEA Project in Jakarta, Indonesia (BAM International Projects, 2020)

4.5.2 Definition & Quantification of inputs & outputs

Similarly to the cases analysed above, the evaluation of the implementation of BIM in IKEA Project in Jakarta requires the detailed definition of the inputs and outputs to be considered. This stage is significantly important for the evaluation procedure because each project involves multiple different positive and negative costs. Therefore, after a series of discussions with the Project and the

Construction Manager of the specific project, the essential data regarding the costs and benefits were collected.

The inputs mainly involve the cost of the software that was required during the whole construction phase, the hardware that was acquired and the cost of personnel. It should be mentioned that because of the large size and the requirements of the project, two subcontractors were involved for the Structural and MEP works of BIM. Particularly, these subcontractors were handed over the creation of the drawing for the concrete elements of the building including all the five floors. BAM Infra, the partner of BAM International for infrastructure connections in the Netherlands, was responsible for the Ground Floor (GF) to the Level 2 (L2) while Archetype, a local Indonesian subcontractor was responsible for Basement 2 (B2) to Basement 1 (B1). Moreover, BAM International worked in cooperation with Denki, the MEP subcontractor in order to produce the drawings of the steel elements and MEP drawings of the five-storey building.

Regarding the outputs, these mainly concern the time that was saved during the production of the drawings because BIM applications were used. In order to specify the monetary amount that is considered as a profit for the contractor, the time that was actually required and the time that would be required conventionally, are estimated. In addition, reduction of waste of materials was achieved especially regarding the quantity of rebars. However, this reduction was mainly considered as a profit for the client. Following, there will be a detailed analysis of this benefit. Moreover, although BIM implementation was a requirement from the client from the beginning of the tender phase, there was no added value in the contract for the contractor. Finally, a few other significant benefits were remarked and will be described thoroughly. The detailed calculation of all of the inputs and outputs considered is presented on Fig. 20, Appendix D & Appendix E.

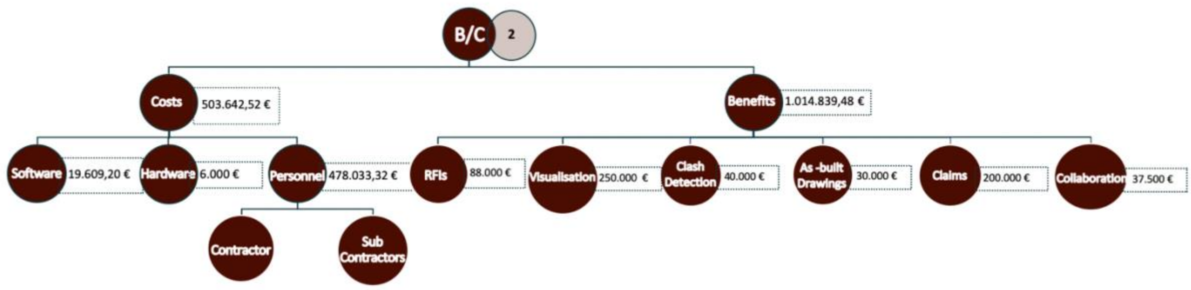

Figure 20 Quantification of Costs and Benefits in IKEA Project

Inputs

- Software

The BIM applications that were used in Jakarta required the suitable software that had to be acquired by the contractor; BAM International. Each software programme involves a different way of costing either depending on the usage duration or the size of the files. Hence, the software acquired and its cost is listed on Appendix D.

- Hardware

In this project, BIM applications were used on-site. Thus, the suitable hardware that could support the software required had to be provided by the contractor. As a result, the costs for the acquisition of the hardware were covered by BAM International. The hardware consisted of desktops and laptops. It should be mentioned that other hardware appliances were used on-site such as tablets, total stations and a drone. However, the cost of these appliances will not be considered in the evaluation procedure. This was decided because these machines were used in other projects in the past. Therefore, the cost to be considered in the evaluation would be based on subjective estimations and would not bring accurate results. Consequently, the total cost of the hardware is 1200 € per user. The number of the users will be defined thoroughly in the following section; the personnel.

- Personnel

The BIM team consisted of 9 people working on site and on different aspects of BIM. Most of the members had different responsibilities and field of working. It should be mentioned that in order to define the total manhours, it was considered that people work 8 hours per day and 24 days per month. To be more precise, the BIM team consists of 2 modellers; 1 working on BIM Architectural drawings and 1 working on BIM MEP drawings. Following, there is 1 modeller on behalf of the subcontractor for MEP plans and 1 modeller on behalf of the second subcontractor for Structural plans. In addition, there is 1 Document Controller working on Team Project and Sharepoint, responsible for the coordination and the distribution of the documents. The subcontractors produced in total 1,021 sheets of detailed drawings which are utilised in the execution phase in combination with the 906 sheets produced by BAM International and MEP subcontractor, Denki. The cost of personnel is shown in detail on Appendix D.

Outputs

Tangible

- Production of Drawings

According to the Construction Manager, there was significant amount of time saved during the production of the drawings. The employment of BIM applications improved the quality of the drawings providing much detail and at the same time made the production of them faster. This benefit can be assigned monetary value by comparing the time the production of drawings took with the usage of BIM and the time it would take if the production had been done with the conventional methods. Given that the production of sheets of drawings involve BAM International, Denki and the two subcontractors; Archetype and BAM Infra, the quantification of the time and cost saving will consider all the human resources. It should be mentioned that in order to calculate the hours needed in order to produce drawings with the conventional methods, it was assumed that there are needed 25 hours for the production of one sheet of drawing. Therefore, the following results emerge.

Intangible

- Value Engineering

This benefit refers to the degree that a technology or process can improve the engineering services provided by a contractor to the client. The implementation of BIM applications in IKEA Project offered this benefit which is hard to be quantified. Particularly, it helped the company achieve BIM LEVEL 2 regarding the department of BAM International in Indonesia. Consequently, this constitutes an advantage for the company for future projects as it helps it offer projects of good quality.

Opportunity to gain time: BIM applications helped BAM International save time from specific activities. To be more precise, the efficient visualisation that the 3D model and 4D planning offered in combination with the Document Management System of BIM enabled the contractor to justify the time delays. Thus, the client accepted these delays and this contributed in avoiding the Liquidated Damage. It should be mentioned that there were several time delays because the owner made changes. As a result, the contractor had to adjust to these changes. This led to additional work which lasted extra months than the initial duration. These unforeseen delays deviated from the contract time and contractor had to extend the duration. This extension was accompanied with additional cost. This additional cost which is called Liquidated Damage, was equal to 0.5% of the total contract value. However, the efficient visualisation provided by BIM workflows enabled the contractor to justify this time extension, gain extra time and avoid the Liquidated Damage.

The **Total Benefit** that is generated from quantification of tangible benefits is **645.500€**.

Additional Information: For the calculations realised above, the following statements were considered.

- 1 working day consists of 10 working hours
- 1 month includes 25 working days

Cost-Benefit Ratio

After the calculation of the costs and benefits of BIM implementation, their ratio is estimated.
The result of this calculation is:

$$\frac{B}{C} = 2{,}015 \approx 2$$

4.6 British Antarctic Survey – UK Antarctic

4.6.1 General Information

This project is located in UK Antarctic and the contract includes its modernization and other research facilities. The whole construction project consists of 4 individual projects, all located in UK Antarctic and will last between 7-10 years. This will enable British scientists to continue their efforts and deliver world class research regarding crucial issues that our planet faces. The contract involves a joint collaboration between BAM Nuttall, BAM International and Sweco as a designer consultant. The type of the contract is a Partnership with British Antarctic Survey (BAS). It is called New Engineering Contract (NEC) and it is common for government owned facilities. It was proved to be a very workable contract because the risks and responsibilities are between the contractors and the client.

The implementation of BIM Level 2 in the whole project was a requirement set by the contractor. On this location, the construction works take place from November until April because of the weather conditions. Therefore, most of BIM works were completed in the office before going on site. This facilitated the execution phase because the 3D Model, the 4D Model and the Site Data Capturing were employed in order to organise the activities and avoid mistakes in a later stage. The main benefits that were generated by BIM applications involved the reduction of on-site issues, the Clash Detection, the efficient QTO and the Visualisation which encouraged the engagement of the stakeholders. Certainly, the project participants prefer to see the model instead of the 2D drawings and BIM applications showed them how their data is secured and can be used later in the Asset Management phase. The clear definition and quantification of the inputs and outputs of the Framework is given on the following section.

Figure 21 British Antarctic Survey in UK Antarctica (BAM International Projects, 2020)

4.6.2 Definition & Quantification of inputs and outputs

Considering that the employment of BIM Level 2 constituted a requirement from the side of the client, BAM International & BAM Nuttall had to adjust to a steep learning curve. Eventually, BIM implementation was proved beneficial for the contractors and the execution of the project. Firstly, the usage of a CDE helped maintain all the information easily accessible. Moreover, 4D Model introduced the time aspect in the organisation of the activities. Consequently, the earned value of this implementation was the ability to measure how efficient the contractor was. This was possible by comparing the actual progress with the scheduled one according to the 4D Planning. Finally, the employment of Virtual Reality gave the ability to the contractors and subcontractors to "Build it before they build it". The creation of the 3D Model provided them a good understanding of the working conditions and a thorough idea of how the project would proceed.

The detailed substantiation of the costs and benefits in BAS is presented on Fig. 22 & Appendix F.

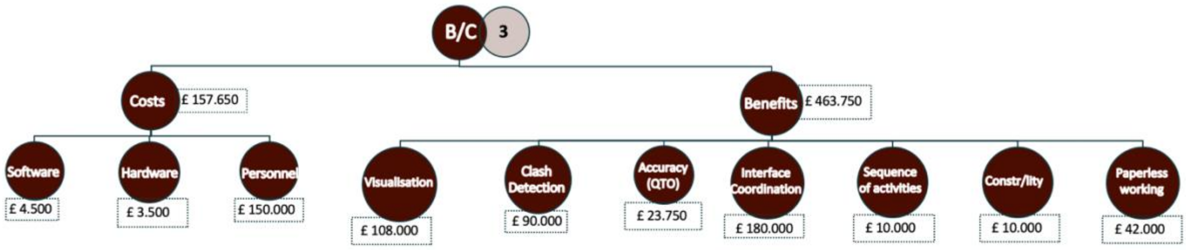

Figure 22 Quantification of Costs and Benefits in BAS

Inputs

- Software

The software that was required in order to use the multiple BIM applications involved the following programmes; Revit, AutoCAD, Autodesk LIVE, Navisworks Manage & Solibri. The cost of the software is estimated based on the licenses they were needed. The final cost was estimated £300 per month. Considering that the software has been used for 15 months so far, this equals with £4.500 for the whole project.

- Hardware

Given that most of the BIM works were implemented in the office, there was no need to acquire much new hardware for the specific project. Particularly, the hardware involved iPads and screens. The monthly cost for the hardware was £210 which generates a total of £3.150 for the whole project so far.

- Cost of personnel

Sweco as the designer consultant of this project was also responsible for delivering the biggest part of the 3D Model regarding the architectural and structural parts. Therefore, BAM Nuttall and BAM International received this model and continued working on it. Hence, there was no need for many people to work explicitly on BIM. In order to calculate the cost of personnel, the working hours of BIM Engineer will be taken into account. This generates a cost of £10.000 per month and, subsequently, £150.000 for the whole duration.

Outputs

- Visualisation of Risks and Opportunities

BIM applications facilitated the modelling of the earthworks; a task that was quite demanding considering the challenging location of the project. As a result, there was a reduction in the waste of materials. Particularly, BIM implementation helped in minimising the rehandling of material. Precisely, the rehandling of 7.200m^3 of rocks was avoided. Considering that this would cost £15/m^3, this benefit produced a gain of £108.000 for the contractor.

- Clash Detection & Design Changes

According to the BIM Engineer of BAS, the 3D model enabled him make more accurate drawings and resolve conflicts on-time and faster comparing to the traditional methods. Precisely, there was a difference of 600 hrs in the situation with and without BIM and 6 people were needed. Therefore, there was a saving of 3600 hrs and considering a rate of £25/hr this generates a benefit of £90.000.

- Accuracy of Estimate

The employment of cost estimating software allowed the contractor to estimate and monitor cost according to the design changes during the Execution phase. Therefore, the 3D model was used for QTO and reduced the time required significantly. To be more precise, there was a saving of 950 hrs which, multiplied with the hourly rate of the Engineer produces a benefit of £23.750. However, an overall check of the calculations was still required.

- Interface coordination & Sequence of activities

The employment of the 4D model in planning with the usage of Synchro Pro & Navisworks software generated a remarkable profit for the contractor. The whole planning procedure was facilitated and carried out with higher accuracy. As a result, there was a saving of 3.200 hrs regarding the coordination of interfaces and 400 hrs for the sequence of activities which resulted to a monetary benefit of £80.000 and £10.000, respectively. Additionally, the higher definition of the construction program and the accuracy in planning in combination with the less conservative floats contributed in a decrease of the total duration of the project. Precisely, 2 weeks, associated with £50.000 running costs per week were saved. All the above resulted to a benefit of £190.000.

- Constructability

The BIM team arranged multiple meetings in order to review the 3D model and discuss on the constructability of the project according to the 4D planning. This helped the contractor save time and specifically, 400 hrs which led to a benefit of £10.000.

- Paperless way of working

In general, the usage of technological means allowed the contractor carry out tests and records on site. Subsequently, this reduced paperwork and the procedure of re-entering data into computer at the end of the shift of the employee. At the same time, it allowed Engineers be on site for longer and continue with the works. Eventually, this way of working saved 420 hrs of working for 2 Engineers and considering a rate of £50/hr per Engineer, it generated a benefit of £42.000.

The **Total Benefit** that is produced from the above calculations is **£463.750**.

Cost-Benefit Ratio

After the calculation of the costs and benefits of BIM implementation, their ratio is estimated and the result is the following.

$$\frac{B}{C} = 2{,}941 \approx 3$$

4.7 Conclusion

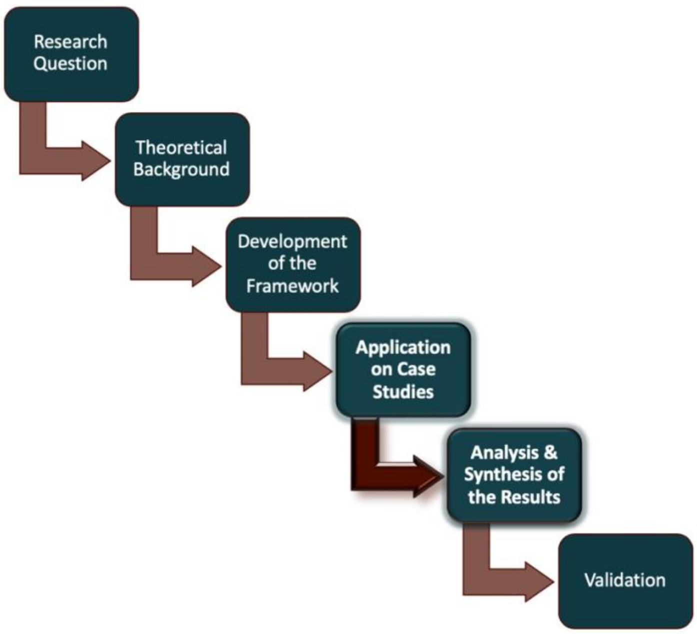

Figure 23 Stages of the Research - From Application to Analysis

The present chapter involved the Application of the proposed Framework on 5 Case Studies; all construction projects of BAM International located abroad. This Application is an essential part of the research and aims to present to the reader the way this Framework works and the results it generates. Hence, 5 projects were chosen in order to conduct an ex-post evaluation on BIM Implementation. As already mentioned, the particular conditions of the project have an impact on the costs and benefits of BIM. Therefore, in each case, the general information of the project was given initially.

Consequently, based on the interaction with experts, the definition and quantification of inputs and outputs was analysed. At the end, the B/C ratio was calculated. After the application of the Framework on 5 Case Studies, the researcher is able to answer the Research Sub-question 4 which is the following:

Sub-question 4*: Which information is required in order to assign monetary value to the tangible benefits of BIM?*

In order to answer this question, the researcher conducted an extensive literature research and then interacted with people that worked actively on each of the Case Studies. When the first round of discussions was completed, she was able to define the list of benefits that would be included in the Framework. Following, her objective was to find the way to assign monetary values to those benefits and particularly the ones of tangible nature. In this way, the B/C ratio would be calculated and the evaluation of the costs and benefits would be accomplished.

As a matter of fact, the substantiation of the benefits constituted the most challenging part of the quantification procedure. The two possible ways to calculate their monetary value would be based on the saving of cost or the added value that BIM Implementation offers. Particularly, the saving of cost can acquire two sources; the saving of time and the reduction of waste. Thus, regarding the saving of time the duration of an activity with and without BIM is required. Then, the difference of these two durations is multiplied with the wage (per hr/day/month) of the staff. The result is the saving of cost for the specific activity due to BIM usage. For example, in order to evaluate the benefit generated by the Clash Detection or the As-built drawings that the 3D model offers, the time that is actually needed is subtracted by the time that would have been required without the usage of the 3D permanent model. Additionally, in order to monetise the benefit generated by the 4D model, the pace of the progress made with the use of it in Moín, is benchmarked against the pace of the progress that was remarked before the use of 4D.

With regards to the reduction of waste, the quantities of materials calculated with and without BIM applications are also quantified. Following, the difference of these two quantities is multiplied with the price of the specific material (per $m/m^2/m^3$). Hence, the saving of cost due to the reduction of waste of materials emerges. For instance, on BAS Project, the 3D model and, particularly the modelling of the earthworks, enabled the visualisation of risks and opportunities. Therefore, a remarkable quantity of materials and consequently the associated cost, was saved. Finally, the added value could be quantified based on two ways. Firstly, the price of BIM on the BOQ which is a cost for the client but a profit for the contractor and secondly, by additional value that BIM applications offered by enhancing a particular part of the whole performance of the contractor.

When the quantification of the benefits is completed, and the costs are also recorded, the B/C is calculated on the Framework. The B/C on the 5 Case Studies ranges from approximately 1 to 8. The interpretation of this ratio and the results is analysed in the following chapter.

5. Results

5.1 Introduction

While the quantification of Costs and Benefits, which was carried out in chapter 4, constitutes the first and most important aspect of the Framework, the results that are finally produced are also useful and important for the contractor. The interpretation of the ratio and the examination of the different sources of the costs as well as the profits can provide the contractor with effective insight and knowledge regarding BIM applications. Moreover, they can raise awareness within the AEC industry on the topic of the multiple advantages and barriers of BIM methodologies. Hence, the analysis of the results will be aimed on this chapter of the present report. The results generated in the previous chapter are shown on Table 2.

Alongside with the interpretation and the analysis of the results that the Framework generated on the Case Studies presented above, the impact that these results can have on BIM strategies should be explored. Considering the recent introduction of this innovative way of managing and creating technology, this research strives to define the way these results can have a valuable impact on BIM deployment for the side of the contractor. Thus, a synthesis of the results will be carried out in order to show how this standard method proposed can be adapted efficiently. Eventually, by the end of this chapter, the researcher will have the sufficient information in order to answer the Research Sub-question 5.

Table 2 Summary table of results of Case Studies

Project	Type	Total Cost of the Project	Total Benefit	Total Cost of BIM	B/C ratio
APM Terminal	Marine	€ 500.000.000,00	€ 3.214.430,00	€ 398.625,00	8,06
LCA	Building	€ 95.000.000,00	€ 2.727.991,26	€ 695.005,22	3,93
Museum of the Future	Building	€ 204.229.663,11	€ 1.719.578,26	€ 1.504.000,00	1,14
IKEA Project	Building	€ 40.000.000,00	€ 1.014.839,48	€ 503.642,52	2,01
BAS	Building	£ 28.783.627,00	£ 463.750,00	€ 157.650,00	2,94

5.2 Interpretation of B/C ratio

5.2.1 APM Container Terminal – Moín, Costa Rica

As already mentioned in section 4.2, the B/C ratio calculated for the specific project is approximately equal to 8. The cost and benefit ratio for the APM Terminal in Moín depicts that for $ 1 invested in BIM implementation, $ 8 were gained by the contractor. Hence, the result of the evaluation of this implementation is considered significantly beneficial for the side of the contractor. It should be remarked that it accurately depicts the actual situation regarding the costs and benefits that were required and gained. The project was completed recently and therefore, it was possible for the Engineers and the members of the BIM team to capture the results of BIM applications and their impact on the execution of the project. In addition, BIM implementation in the specific project was not a requirement from the client but an initiative of the contractor. Therefore, the whole team worked hard in order to enhance the performance of the company and generate tangible and intangible benefits from this innovative technological means of managing information. In additional, the people that worked in Moín admitted that an important reason that helped them increase their profit was the fact that BIM team actually worked on the construction site. This helped the contracting company optimize the procedures taking place during the execution phase by updating the models on a daily basis. Finally, the most remarkable reason that helped the contractor attain such a high benefit was the fact that the impact of BIM applications was directly detected on activities which are on the critical path. This means that a high amount of money was saved because the decrease in the duration of the critical activities led to a decrease of the operational costs. Eventually, people that worked on-site worked together with the researcher in the quantification of the benefits and achieved high accuracy in the calculations. Thus, the high value of the factor was expected by them.

5.2.2 London City Airport (LCA) – United Kingdom

After analysing the costs and benefits of BIM implementation for the project in London City Airport thoroughly, the B/C ratio emerged approximately equal to 4. Although the ratio is relatively high, the Engineering Manager claimed that the Quantification procedure was quite challenging because it was hard to identify was caused because of BIM. As a result, conservative estimates and assumptions were attempted.

Also, he strongly supports that if there was a system able to capture all the events happening on-site, then the quantification would be easier and more accurate. Therefore, this lack of a procedure gives the feeling that not all the benefits were captured and that the actual ratio could be slightly higher. Thus, this standard procedure can contribute in recording the essential information and finding the balancing act of capturing the benefits and the time required in order to quantify these benefits.

5.2.3 Museum of the Future – Dubai, UAE

In section 4.5, following the quantification of costs and benefits, their ratio was calculated and was almost equal to 1,12. To be more precise, this result indicates that for every 1€ invested by the contractor on BIM applications, 1,12€ was gained. This result is significantly low and unexpected considering the conditions of the project. During all the rounds of interviews and discussions, the people that participated in the specific project claimed that, because of its complexity, “Without BIM, the construction of this project would be impossible”. Clearly, this intangible benefit that BIM applications offered, was not depicted in the result of the quantification procedure.

Moreover, this low ratio can be justified due to the particular conditions of BIM implementation in this project. It should be mentioned that the BIM deliverables for the client are related to the management and delivery of information in order to improve the efficiency of the operation and maintenance of the building assets later in the future. However, the contribution to the project team and the whole execution procedure exceeds the scope of the client. Firstly, there are fewer problems during the construction phase related to design errors, coordination and construction errors. In addition, the visualization thanks to BIM provides a better understanding of the proposed design and facilitates decision making. Furthermore, BIM applications offer a beneficial impact regarding the control of construction costs and the arising of claims. To be more precise, BIM application could identify thoroughly the changes by the client and in this way, increase the rate of acceptance of the claims by him. Finally, the 3D Laser Scanning used on site surveying, data processing and the interpretation of the results would have been outsourced to a 3rd party if the company did not possess the expertise and the equipment to take over it.

To conclude, it was claimed unanimously that considering all the benefits above alongside with the healthy working environment and the avoidance of any accident, BIM implementation enabled BAM verify the constructability of this complex design and deliver this challenging project in an efficient and safe way.

5.2.4 IKEA Project – Indonesia, Jakarta

Following the definition and quantification of costs and benefits for IKEA Project in cooperation with the Project Manager and the Construction Manager, the B/C was calculated. The result was approximately equal to 1,93. Although it can be characterized as low especially in comparison to the rest of the projects, this ratio is actually considered that it reflects reality. To be more precise, BIM implementation in the specific project was an initiative of the contractor. Therefore, the usage of BIM applications was done only in order to facilitate the execution of the project and enhance the performance of the company. As a result, different workflows would be used gradually during the implementation. Considering that so far only the 3D model and its benefits have been exploited by the project team, the quantification only focused on the benefits which emerge from the specific workflow.

Hence, the Project Manager ensured the researcher that BIM implementation in the specific project is still at an initial phase and more benefits are to be gained in the future. Of course, he admitted that improvements in the whole usage of BIM are to be pursued in the future of this project and of the company as well.

5.2.5 British Antarctic Survey (BAS) – British Antarctic

According to section 4.7, the B/C ratio for the project in BAS was calculated approximately equal to 3. The result of the calculation was expected by the BIM Engineer and is thought to reflect the actual situation. Particularly, the BIM Engineer claimed that the costs can actually be higher because the 3D model was firstly created by the Designers of the project. However, Design was not included in the contract of BAM International & BAM Nuttall, and was outsourced to another Dutch construction company. Therefore, the hours that were spent by the designer were not considered as a cost in the quantification of this research. At the same time, there were multiple intangible benefits which could not be assigned a monetary value. In addition, the Engineer claimed that there are numerous unknown unknowns which are hard to be captured and quantified. Hence, the B/C ratio was calculated conservatively and the result reflects reality. Eventually, it was also claimed that if there was a higher budget for BIM implementation, then other collaborative software, and the essential hardware, could be used in order to offer more opportunities and benefits to the contractor.

5.3 Cost and Benefit Analysis of Case Studies

5.3.1 Cost Analysis of BIM Implementation

Costs constitute the main and most indispensable variable in the whole procedure of BIM implementation in a construction project. Moreover, it is also important to extend the lifecycle of evaluation from ex-ante to ex-post implementation. This extension enables changes in organizational objectives, the system and learning processes to be incorporated into the evaluation. In this way, the contractor can adjust the BIM strategy he possesses depending on the results of the evaluation and thus, aim for the higher benefits.

Table 3 Detailed Costs of BIM Implementation of Case Studies

Project	Total Cost of BIM	Total Cost of the Project	Cost of BIM of the Total Cost (%)	Cost of Software (%)	Cost of Hardware (%)	Cost of Personnel (%)
APM Terminal	€ 398.625,00	€ 500.000.000,00	0,08	3,38	1,44	95,18
LCA	€ 695.005,22	€ 95.000.000,00	0,73	13,97	2,56	83,47
Museum of the Future	€ 1.542.658,00	€ 204.229.663,11	0,76	0,81	1,70	97,49
IKEA Project	€ 503.642,52	€ 40.000.000,00	1,26	3,89	1,19	94,92
BAS	£ 157.650,00	£ 28.783.627,00	0,55	2,85	2,00	95,15

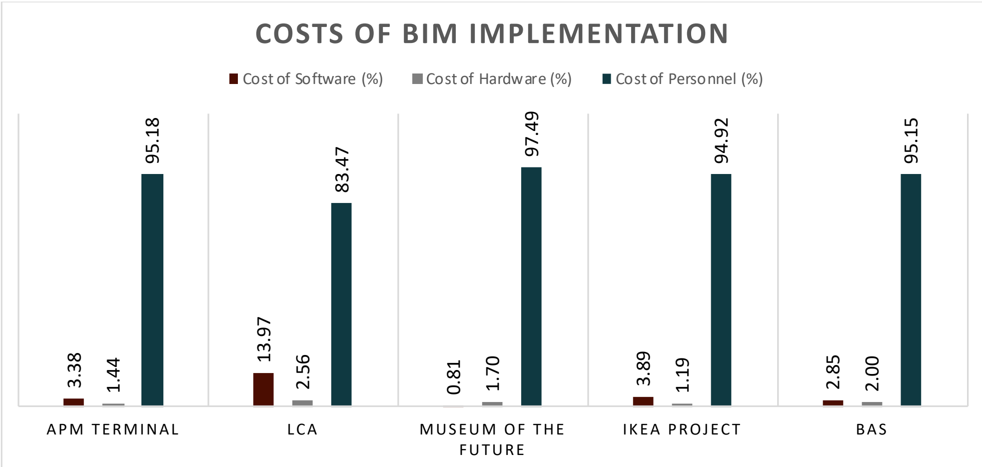

Figure 24 Percentage of Different Costs of BIM Implementation

Therefore, a Cost Analysis is aimed among the 5 different Case Studies in order to extrapolate useful conclusions. According to Table 3, the Cost of BIM implementation constituted a very low percentage of the Total Cost of the project. Also, according to Table 4, it is obvious that in all of the Case Studies, the percentage of the benefit is significantly higher than this of the cost. Therefore, the BIM Implementation is proved beneficial for all of the projects.

In addition, on Table 3, the percentage of the total cost that each category (software, hardware & personnel) required, is shown. According to the table, in all of the Case Studies, the higher cost was required for the working hours. It should be mentioned that in LCA, the cost of software constitutes the 13,97% of the Total Costs. In other words, the cost of software and hardware that had to be acquired is relatively extremely low comparing to the costs required for the human resources. Thus, the personnel constitute the variable that should be given attention in order to attain beneficial results for the side of the contractor through the usage of BIM applications.

5.3.2 Cost of Personnel

As mentioned above, the cost of personnel which is required for the efficient usage of BIM applications is remarkably higher than the ones required for software and hardware acquisition. The reasons that lead to a significant quantity of working hours and therefore high cost of personnel vary but could be divided into 3 levels. Firstly, given the innovative character of BIM methodologies, the whole BIM procedure can be challenging for the contractor. As already mentioned earlier, the level of training and education of people working in AEC industry is still low, therefore the usage of BIM applications requires time. Secondly, the difficulty of the project itself can lead to increased amount of work needed by the BIM team. The complex design, the special conditions of the construction site such as the location and special characteristics of the project can constitute a barrier in the implementation of BIM. Finally, given the recent introduction of BIM methodology in AEC industry, there is still lack of experienced staff and expertise. Therefore, it is highly possible that mistakes can occur in the employment of BIM applications and software. As a result, these mistakes can lead to time delays. For example, a possible mistake would be the offline working of BIM team. This way of working could lead to conflicts once the plans are integrated to each other and their solving would require additional working hours.

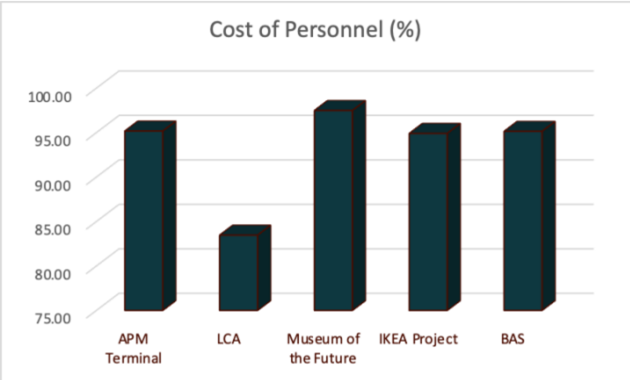

Figure 25 Cost of Personnel as a percentage of the total cost

According to Fig. 25, the project which required significantly high cost of personnel was Museum of the Future. The cost for working hours was 97,49% of the whole while the cost of software was almost 1% and the cost of hardware 1,70%. However, according to the BIM team of this project, the remarkably high cost of personnel can be totally explained. Firstly, the unique and complex design of the project constituted a challenging part of the creation of 3D model. Therefore, the creation of the 3D model was time consuming and required many people. In addition, the demanding conditions of the specific project required a BIM team of 7 people which was the largest BIM team in comparison to the rest of the Cases investigated. Therefore, all the above can explain the high cost for human resources that was remarked.

However, according to the DC Manager of BAM International, the high values of the cost of personnel can be fully explained regardless the 3 levels discussed above. Based on his knowledge and expertise, he claims that DC is all about people that work together and create as well as manage information. This innovative way of managing and creating information would undoubtedly require long working hours in order to integrate all the different parts into one unique 3D model. While this procedure is time consuming and leads to an increased cost, it also brings people into one team. Therefore, the people that conventionally would work separately in an Architectural, Structural and MEP team are now integrated in one BIM team. Moreover, in each BIM team there is only one BIM Manager in contrast to the conventional 2D methods when each discipline (Architectural, Structural and MEP) requires their own leader. Subsequently, the communication is less time-consuming since all the Engineers and Draftsmen work within the same team. This also leads to less need of human resources because people are now working on the same model which is constantly updated. Therefore, conflicts and errors are detected on the spot and solved faster in comparison to traditional 2D procedures. In addition, although the cost of personnel is high comparing to cost of software and hardware, the size of the BIM team is small in comparison to the whole Project team. For example, the BIM team in IKEA Project constitutes only the 5,15% of the site office human resources. Subsequently, even if the cost of personnel is the highest among the 3 direct costs analysed, can be totally explained considering that the human element is necessary in order to achieved efficient management of information.

Considering all the above, the question that arises is whether the significant number of hours needed by the human resources for BIM implementation is exploited in the optimal way. In other words, the evaluation of costs and benefits indicated the remarkably high cost of personnel in relation to the other two types of cost. Therefore, in order to attain higher profits, the experts should focus on the proper utilisation of the human resources.

To be more precise, the contractor should adopt methods to control the time that is devoted specifically on BIM applications. In this way, he would be able to understand the sources of the shortcomings. Firstly, as already mentioned above, a lack of expertise or knowledge could be the reason of spending long working hours and this would show that the efficiency of the personnel should be strengthened. Additionally, another reason of spending much time could possibly be the usage of inappropriate software of hardware. In this case, the BIM team should adjust on the requirements of the specific project and acquire the equipment that is needed.

Although, the CBA that was conducted on 5 Case Studies achieved to evaluate the usage of BIM, it was mainly based on self-reporting from the side of the experts who used the technical reports and accompanied by their personal experience. One of the main results was the significantly high cost of personnel. Hence, there stems a need to develop methods and tools to measure the time that is spent on BIM applications. The proposed Framework involves the on-going record of the working hours in order to calculate the cost of personnel. In this way, the contractor can potentially be able to control the working hours and define the weaknesses of the personnel. Hence, they could altogether arrange team sessions on a regular basis aiming to enhance their performance and possibly decrease the working hours.

5.3.3 Benefit Analysis of BIM Implementation

After conducting 3 rounds of interviews and discussion with the Project Manager, the Construction Manager and the BIM Engineer of each Case Study, the quantification of the tangible benefits was completed. The Table 4 shows the values of the benefits per project. Undoubtedly, the size of the benefit among the cases varies remarkably due to the different conditions and running costs of each construction site. Apart from the size, the workflow and particularly the category of the benefit that generated the highest profit also vary. This is completely understandable due to the particular characteristics of each case.

Table 4 Benefits of BIM Implementation of Case Studies

Project	Total Benefit	Highest Benefit	Benefit of BIM (%)	Workflow of the Highest Benefit	Category
APM Terminal	€ 3.214.430,00	€ 2.962.080,00	92,15	4D Planning	Interface Coordination
LCA	€ 2.727.991,26	€ 1.248.440,00	45,76	3D Permanent Model	Requests for Information
Musem of the Future	€ 1.719.578,26	€ 109.865,85	6,39	3D Permanent Model	Clash Detection & Design Changes
IKEA Project	€ 1.014.839,48	€ 369.339,48	36,39	3D Permanent Model	Production of Drawings
BAS	£ 463.750,00	£ 190.000,00	40,97	4D Planning	Interface Coordination & Sequence of Activities

While the categories of the benefits differ, in 3 out of the 5 cases investigated, the workflow that generated the highest benefit is the 3D model. The next most profitable workflow is the 4D planning. This remark was again totally expected because according to the experts that work in the projects, in most of the cases the BIM applications are not fully exploited. To be more precise, especially in IKEA Project, the BIM implementation is still at an initial phase. This means that the experts expect more and higher benefits when the 4D planning or the Site Data Capturing are employed later in the future.

On the other hand, in the rest 2 of the projects, the 4D Planning was the common workflow that produced high benefit. Moreover, in both of the projects, the Interface Coordination facilitated the execution and generated a remarkable profit for the contractor. Particularly, as shown on Table 4, in APM Terminal in Moín, the Interface Coordination produced 92,15% of the total benefit gained by the contractor. This percentage is considerably higher to the rest of the categories and could mean that the usage of 4D Planning for efficient coordination of interfaces and activities could lead to significantly valuable profits. Consequently, this is the reason why the majority of the interviewees claimed that there are more benefits to be gained later when more BIM applications are employed.

5.4 Synthesis of the Results

The analysis of the results carried out in sections 5.1 and 5.2 can lead to beneficial conclusions regarding the BIM strategies of the contractor. Therefore, in this part, the synthesis of the results will be achieved by considering the quantitative and qualitative parts of the research. On the one hand, the quantitative part which refers to the calculation of B/C ratio helps understand the most important sources that generate positive and negative costs. On the other hand, the qualitative part which involves the discussion with interviewees helps formulate the lessons learnt and consequently define the points of improvement. These two parts alongside with the analysis made above help the researcher form the synthesis of the results which can shows the way the findings of this research can optimise the BIM employment of the contractor.

5.4.1 Establishment of BIM Standards

Quantification of Costs and Benefits

According to the majority of the interviewees, the lack of standard procedures regarding BIM Implementation in construction projects was considered responsible for the low ratio in some of the cases. Most of them claimed that if a standard method such as the Framework proposed was utilised, then the benefits would most probably be more quantifiable and, hence, higher.

To be more precise, the interviewees highlighted that the information is not recorded on time. As already mentioned, one of the problems in the quantification of the benefits is the lack of relevant data. Thus, if a standard method was adapted during the execution phase, the necessary information regarding BIM benefits and mistakes would be recorded. In this way, the contractor could have a sufficient view of the progress and make changes when needed. Therefore, the performance would be enhanced and there would be a constant monitoring of the positive and negative costs.

Cost of Personnel

In addition, standard procedures would potentially affect the working hours of human resources required. Particularly, if general guidelines were established for all the projects, BIM implementation would be more comprehensive and less complicated. The members of the BIM team would be more trained and have a better understanding of the areas they should give their attention. This would also ensure better collaboration within the BIM team. As a result, valuable amount of time would possibly be saved. However, it should be mentioned, that still each project would need its tailor-made solutions and handling.

5.4.2 Critical Activities

The application of the Framework on the project in Moín had a significantly high result. One of the main reasons that generated this result was the fact that BIM affected critical activities. As already mentioned, when the duration of the critical activities is reduced, then the whole duration and thus, the operational costs are also reduced. As a result, the benefit is much higher comparing to a non-critical activity. This remark shows that the contractor should give more attention to the activities which are on the critical path because these would have a higher impact on the final result. Hence, if he wants to maximise his profit, a profitable idea would be to employ BIM applications efficiently on critical activities.

5.5 Cross-Case Analysis

This analysis aims to make comparisons based on the results of the 5 different Cases that were studied on chapter 4. The comparisons will be based on a Sensitivity Analysis regarding the B/C ratios that were calculated after the application of the proposed Framework on each case in order to verify the robustness of the results. The reason that this part is needed is the variance on the results and specifically on the B/C ratios that were generated from the application of the Framework.

5.5.1 Sensitivity Analysis

Sensitivity Analysis is employed in order to show how sensitive is a model when the parameters and the data that build it are modified. The results of this analysis can have useful implications regarding the relationship between the inputs and the outputs of the model (Salciccioli, Crutain, Komorowski, & Marshall, 2016). Even though all of the projects possess unique conditions and characteristics, there is high variance in the results of the B/C ratios. Sensitivity Analysis is applied based on assumptions that are different from those used in the first analysis (Chin & Lee, 2008). Particularly, the variables that the model is comprised of, are assigned different values according to assumptions and trials made by the researcher. Therefore, Sensitivity Analysis is used as a way to establish if these variables are accurate and how sensitive they are to any fluctuations.

Hence, based on the theory above, the Sensitivity Analysis of the proposed method will involve some assumptions regarding the Costs that were considered. Particularly, the researcher will assume a positive and negative change of 1% for each different cost in all of the 5 Cases. Thus, for every Case, every cost will be explored individually in order to indicate how sensitive the B/C ratio is in relation to the specific type of cost. The result of the Analysis will also be given as a percentage. In this way, the audience will easily understand what is the impact on the ratio in percentage terms for a positive or negative change of 1% in each type of the 3 different costs. In other words, when the Sensitivity Analysis is completed, the reader will know what is the % change on the B/C ratio for a 1% positive or negative change on the Cost of Software, Cost of Hardware or the Cost of Personnel.

Subsequently, in this point, the results of the Sensitivity Analysis for the 5 Case Studies are presented on graphs and in detail on Appendix G. Particularly, the graphs below depict the impact that was calculated firstly on the B/C ratio and secondly on the Total Costs of BIM Implementation. The impact was estimated for an individual assumption of 1% positive or negative change on each type of cost. The 1% change was chosen in order to indicate the impact that one 1 unit of change has.

Cost of Software

According to Fig. 26 & 27, it is clear that the cost of software is not a remarkably sensitive variable. To be more precise, for a change of 1%, either increase or decrease, in the cost of software, the B/C ratio and the Total Costs have a difference of maximum 0,14% in all of the Cases. However, the Case Study in London City Airport indicates a difference of 0,14% when the cost of software is changed by 1%. This percentage which is the highest among the Case Studies is explained because according to Fig. 24, the Cost of Software in LCA constitutes the 13,97% of the Total Costs. Therefore, this evidence confirms that the specific variable would show the highest sensitivity in the particular Case Study. Finally, we see that this variable presents a similar sensitivity in all of the cases as the percentage does not differ a lot among the 5 different projects as it ranges from 0% to 0,14%.

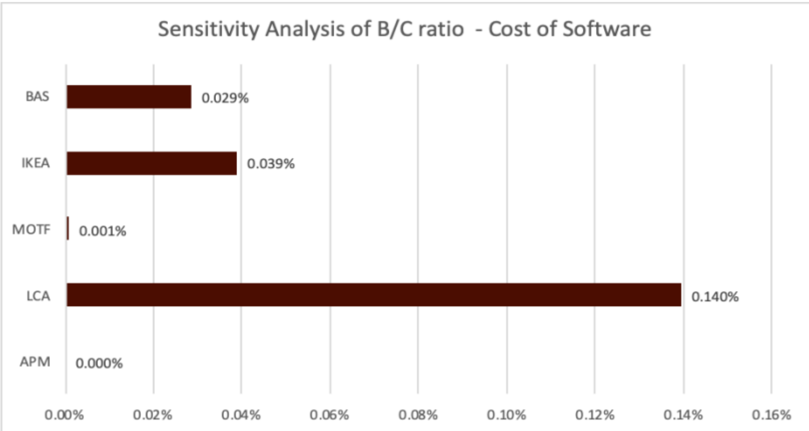

Figure 26 Results of Sensitivity Analysis of the Cost of Software on the B/C ratio

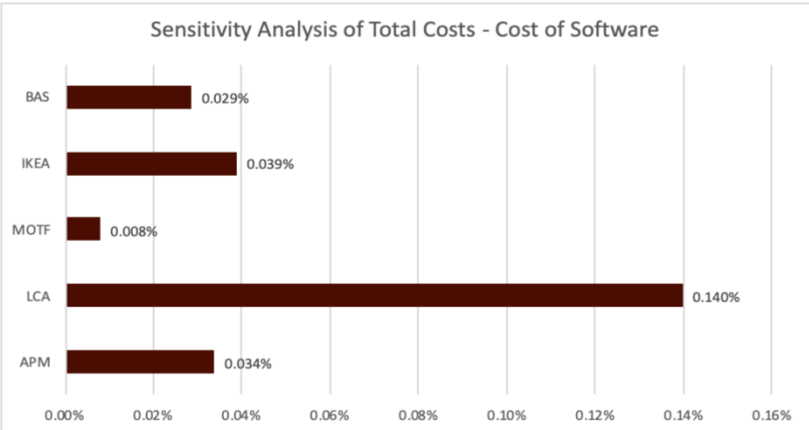

Figure 27 Results of Sensitivity Analysis of the Cost of Software on the Total Costs

Cost of Hardware

Similarly to the Cost of Software, the Cost of Hardware does not possess significantly high sensitivity as a variable as the % impact on the results for a 1% change on the specific cost remains low. Particularly, according to Fig. 28 & 29, a change of 1% on the Cost of Hardware causes an impact of maximum 0,026% on the B/C ratio and the Total Costs. The highest percentage of 0,026% is remarked again on LCA project. This high percentage is explained based on Fig. 24. According to this graph, the Cost of Hardware on the LCA constitutes the 2,56% of the Total Costs which is again the higher percentage of the variable among the 5 Cases. Therefore, it was expected that this variable would show the highest sensitivity in the specific project. However, the sensitivity does not show remarkable variance as the result ranges from 0% to 0,026% and therefore this change is barely noticed.

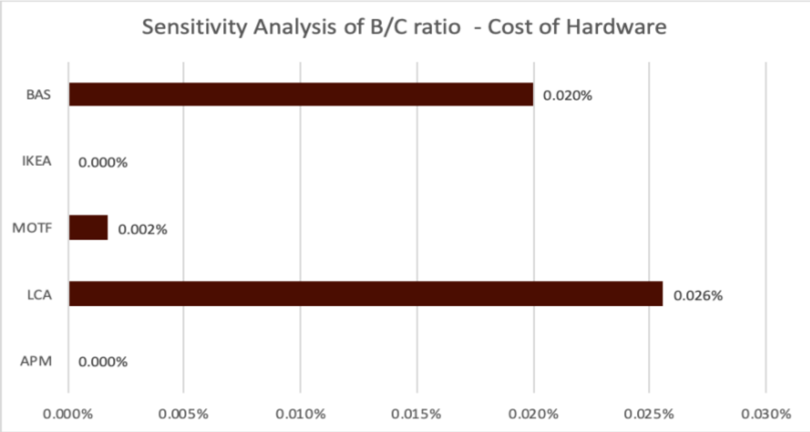

Figure 28 Results of Sensitivity Analysis of the Cost of Hardware on the B/C ratio

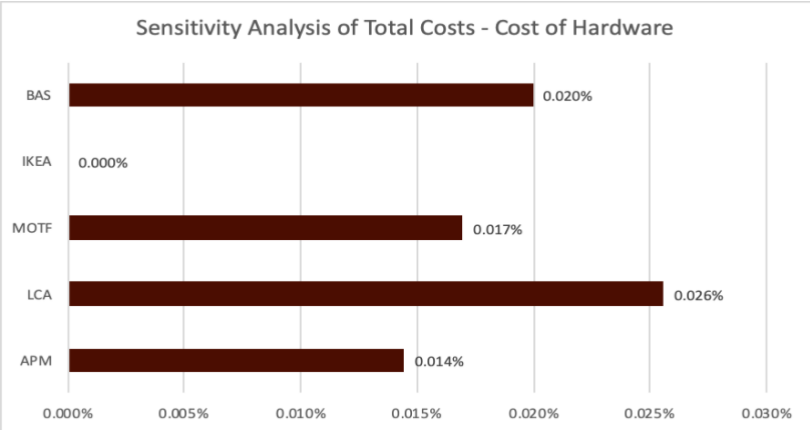

Figure 29 Results of Sensitivity Analysis of the Cost of Hardware on the Total Costs

Cost of Personnel

According to all the Figures above and Fig. 30 & 31, the Cost of Personnel is the variable which possesses the highest sensitivity. To be more precise, for a change of 1% in the Cost of Personnel, the B/C ratio acquires a change of almost 1% in 3 of the 5 Cases. Nevertheless, on APM Project, the change is 0% because the benefits are 8 times higher than the cost. The cost is the denominator of the ratio and thus the result is not depicted. On the other hand, a change in this variable causes a significant impact on the Total Costs. This impact is very clear on the Fig. 31. As shown on this graph, in all of the projects, a change of 1% on the Cost of Personnel leads to a change of almost 1% on the Total Costs. This was expected because the Cost of Personnel constitutes the variable with significantly larger percentage of the Total Costs of BIM Implementation ranging from 83,5% to 97,5% in comparison to the other two costs which range from 0,8% to 14%. Therefore, a positive or negative change in this variable was expected to cause a remarkable impact on the B/C ratio and the Total Costs.

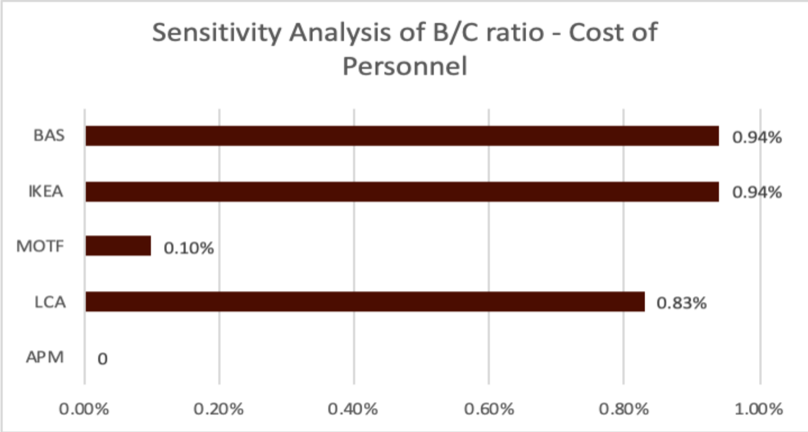

Figure 30 Results of Sensitivity Analysis of the Cost of Personnel on the B/C ratio

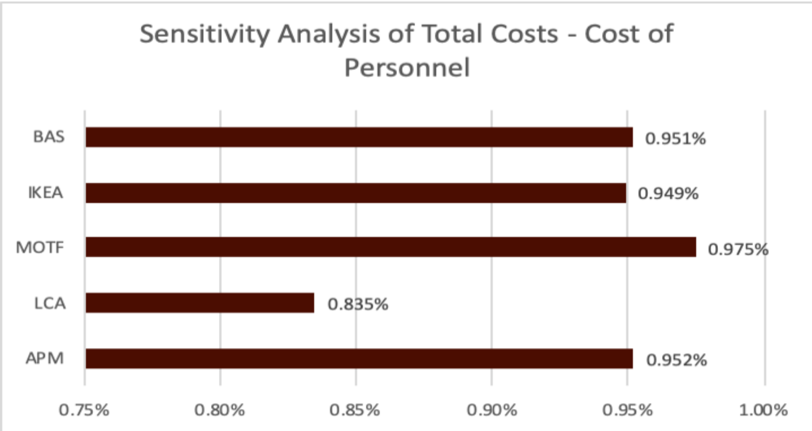

Figure 31 Results of Sensitivity Analysis of the Cost of Personnel on the Total Costs

Likelihood

As mentioned above, the 1% change was selected as an indicative change. Particularly, this assumption shows the results that emerge for every 1 unit of change. Regarding the software, this change could come either by reduction or increase of the project duration or by changing the software used in the whole organisation. This could happen because of the upgrades that companies do regarding operational issues in order to be up-to-date with the changes in the industry. In contrast, the cost of hardware is not very likely to change during the Execution phase as it constitutes a standard amount of money which is required at the beginning of the project in order to acquire the equipment needed. Finally, the cost of personnel can possibly change due to 2 reasons. Firstly, if the duration of the project is reduced or expanded and thus, the amount of manhours changes. Secondly, a source that causes long working hours and thus, high cost of human resources, are the changes that occur during the Execution. Thus, according to the DC Manager, it could change if there is a better understanding and collaboration among the contractor, the designer and the client. This would lead to a smaller number of changes needed and consequently, working hours would be saved.

Conclusion

To conclude, the Sensitivity Analysis that was implemented for the 3 different variables of the costs; the Cost of Software, Hardware and Personnel, proved that the Cost of Personnel is the variable with the highest sensitivity. This means that a change in this variable will also bring a similar change in the Total Costs of BIM Implementation. The most important finding that this Analysis accomplished is that the Cost of Personnel is the most sensitive variable for all of the Cases. Hence, although there is variance on the B/C ratios, all of the projects indicate unanimously a remarkably higher sensitivity on the Cost of Personnel than on the two other types of costs. Therefore, this analysis validates the conclusions that were generated through the analysis of the results. Particularly, the Sensitivity Analysis verifies that the Cost of Personnel constitutes the most sensitive and impactful variable among the three types of costs in all of the Case Studies as was already expected from section 5.3.2. Finally, this analysis does not only validate but also indicates that the impact that this variable has on the Total Costs of BIM Implementation does not vary significantly among the projects as it ranges from 0,835% to 0,975% for 1% change of the variable.

5.6 Conclusion

The present chapter focus on the analysis and the synthesis of the results that stem from the application of the proposed Framework on 5 Case Studies. The aim of this part was to interpret the B/C ratio and clarify its meaning taking into account the specific conditions of each project as well. Moreover, the purpose of the synthesis was to indicate the impact that the present research can have on the BIM strategies of the contracting company. Hence, when the fifth chapter is completed, the researcher is able to answer to the Research Sub-question 5.

Sub-question 5: *In which way do the costs & benefits of BIM implementation inform on the impact of BIM strategies of the Contractor?*

When the application of the Framework on the Case Studies is completed, the researcher proceeds to the analysis of the results that were generated. This analysis explains the impact that the evaluation can possible have on BIM strategies. Firstly, the interpretation of the B/C ratio which ranges from 1 to 8, shows how the special conditions of the project affect the required costs and the expected benefits. Moreover, the analysis indicated that the cost of personnel is remarkably higher than the rest two types of costs and ranges from 83,5%-97,5% of the Total Cost of BIM while the cost of software ranges from 0,8% to 3,55% and this of the hardware from 1,19% to 2,56%. Consequently, the reasons that can possibly cause this high cost of human resources namely the low level of BIM education, the difficulty of the project itself or the lack of expertise were stated. Regarding the benefits, their analysis showed that, so far, the usage of 3D model has generated the highest benefits in 3 of the 5 cases while the 4D model and specifically the Interface Coordination which produced the highest benefit in Moín, seems promising and beneficial.

In addition, a sensitivity analysis is suggested because of the variance of the B/C ratios. The Cost of Personnel is confirmed as the most sensitive variable. Hence, some ways which could potentially decrease the working hours and thus, the Cost of Personnel are recommended by the researcher. These suggestions include the establishment of BIM Standards and the focus on Critical Activities of the project. Firstly, the BIM standard procedures and protocols could ideally save the time spent on BIM Implementation and secondly, the focus on the Critical Activities can save higher amount of money in comparison to the Non-critical ones, as proven on the first Case Study.

The proposed Framework can perhaps be adopted by the contracting company as part of the standard procedures and contribute in controlling the inputs and outputs of BIM Implementation throughout the whole Execution phase.

6. VALIDATION

6.1 Introduction

The last step in the procedure of the Framework development is the validation of it. This stage aims to ensure that the Framework provides the user with sound results and it can be applied in future projects as well. In order to validate the proposed ideas and confirm their reliability, the researcher employed a twofold approach. Firstly, she proposed the application of the Framework in a pilot project which is still in progress in contrast to the rest of the Case Studies. This step aims at extrapolating recommendations and corrections by the Engineers currently working on the specific project and at the same time, confirms the simple and useful functionality of the Framework. The comments for improved from the experts are considered validation of the proposed method. Subsequently, the researcher conducted a short interview with a panel of experts who work on BIM implementation within the Royal BAM Group. This purpose of this part is to verify the replicability of this standard procedure in future projects and establish the impact of this Framework on the holistic BIM strategy of the company. At the end of this part, the researcher answers the last Research Sub-question.

6.2 Application on a pilot project

The purpose of this part is to test the in a real-life case, whilst previously there were analysed only retrospective cases, with incomplete or hard to retrieve datasets. A current real-life case gives this research the opportunity to test the full merits of the Framework by collecting data first hand. The application on this ongoing pilot project is different it is not just another Case Study. It provides the opportunity to verify the reported costs and benefits during the execution and identify aspects that may be forgotten after the completion of the project. The researcher does so by applying this Framework in a current marine project of BAM International.

6.2.1 General Information

As already mentioned, the objective of this Framework is to record all the important events and information on the spot allowing the user to quantify accurately the costs and benefits of BIM applications. Therefore, in order to check the functionality of the method and the soundness of the results a project which is still in progress was chosen. This project is located in Abu Dhabi and involves the construction of a new cruise jetty as shown on Fig. 32 at Sir Bani Yas Cruise Beach. The project was initiated recently and therefore BIM applications, the 3D & 4D model, have been used only for 3 months so far during the execution phase.

Figure 32 Render of Sir Bani Yas Project in Abu Dhabi, UAE (BAM International Projects, 2020)

6.2.2 Definition & Quantification of inputs & outputs

Similarly to the Case Studies, the application of the Framework involved a few rounds of interviews and discussion with people working currently on the project. Firstly, the definition and quantification of the costs that were required was completed and then the quantification of benefits was aimed. In Fig. 33 & Appendix F the detailed monetary values that were given to the positive and negative costs are shown. Following, there is a brief description of them and the generation of these values.

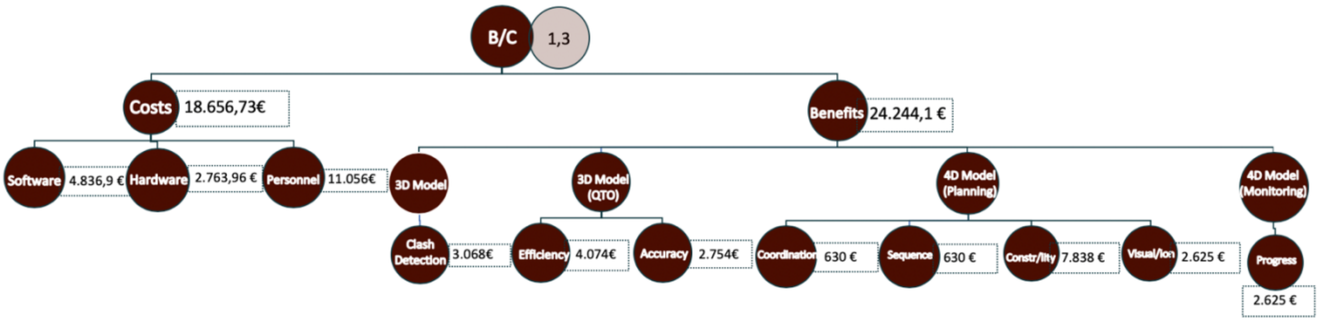

Figure 33 Quantification of Costs and Benefits in Sir Bani Yas

Cost and Benefit Ratio

Based on the inputs and outputs quantified above, the calculation of the Cost and Benefit Ratio for the progress of the BIM implementation so far, followed and was approximately equal to 1,3.

6.2.3 Lack of benefits

One of the significantly important findings of this part of the validation was that most of the benefits were not applicable yet. Nevertheless, according to the people working on the project, they expect to experience them later as the execution phase progresses. Their response shows that they are aware of the benefits they expect and with the usage of the Framework they will be able to quantify them on the spot. In contrast to the rest of the projects that interviewees had to go back in time and track the information needed, in this case, people will be prepared to record the data required in order to calculate the benefits accurately. Hence, this is a first positive sign which indicates that the application of the Framework from the beginning of the project can generate accurate results which totally capture the actual situation.

Indeed, according to Fig. 33, it is clear that many benefits have been quantified. In fact, the number of the benefits that were calculated in this project is higher than all of them in the cases investigated in chapter 4. This amount of benefits quantified is justified because the Framework was applied while the BIM implementation was still at an initial phase. Thus, people working on the project were able to track these benefits in real time, collect the information needed and assign to them monetary values. Moreover, the number of benefits will be higher at the end of the project considering that many benefits are expected to be gained in the future.

6.2.4 Comparison of validation and application

The pilot application of the Framework in a current project enables the researcher to make comparisons based on the results she acquired and verify the results that were generated on chapter 4. These comparisons mainly have to do with the different costs of software, hardware and personnel that was needed as well as the B/C ratio that emerged. The objective of this part is to indicate the differences among the findings of the application and these of the validation. In this way, the researcher aims to show the value that the validation adds in the whole study.

Different Costs of BIM Implementation

According to Fig. 34, the different costs required as percentage of the total cost are given. The project in Sir Bani Yas shows a clear difference comparing to the rest of the projects. To be more precise, the percentage of software and hardware are much higher in the current project than the rest which are almost or totally completed. In contrast, the percentage for the cost of personnel is significantly lower than the rest. However, these findings can be explained considering that the project is now in progress.

Firstly, it should be remarked that the Total Cost of BIM Implementation for the project in Sir Bani Yas is low because the usage of BIM applications is still at an initial phase. Moreover, there are less human resources from contractor's side and specifically one Engineer and a part-time Planner, given that the project is so simple. Furthermore, according to Fig. 34, the Cost of Personnel is 59,26% while the lowest among the other is 83,47%. This application verifies that the Cost of Personnel is the highest among the three costs. However, this low percentage was expected because the BIM Implementation is still going on and the working hours are expected to increase until the end of the project. Particularly, more time will be given by the BIM Engineer and the Planner during the Execution of the project as more aspects of BIM such as the 4D Model will be used. Therefore, the cost of the human resources and consequently the total cost of BIM is expected to rise as the Execution progresses. Lastly, the cost of software and hardware are relatively higher because the total cost is low and thus, the partial percentages are high.

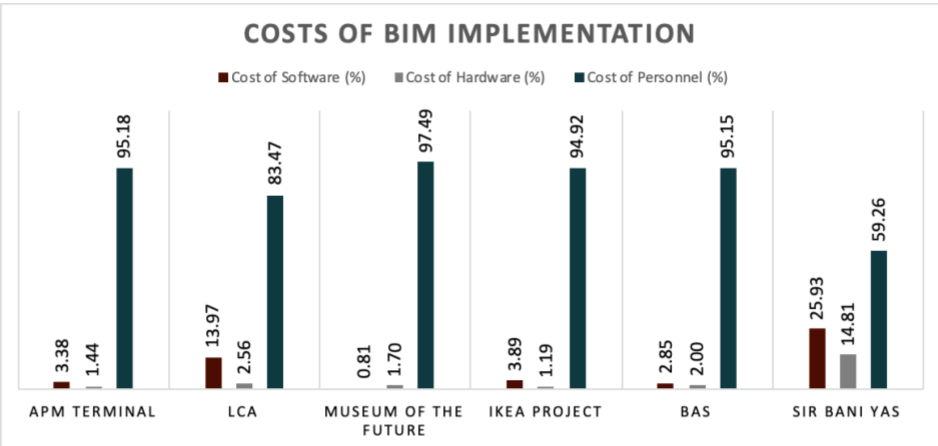

Figure 34 Percentage of Different Costs of BIM Implementation of all Projects

Benefit-Cost Ratio of all projects

Following the comparison of the different costs of BIM Implementation between the Case Studies and the Validation, some comments on the B/C ratio that emerged after the quantification, are made. This part aims to show the importance of the Framework application from the beginning of the project.

Table 5 Summary of results of all Projects

Project	Purpose	Type	Total Cost of the Project	Total Benefit	Total Cost of BIM	B/C ratio
APM Terminal	Case Study	Marine	€ 500.000.000,00	€ 3.214.430,00	€ 398.625,00	8,06
LCA	Case Study	Building	€ 95.000.000,00	€ 2.727.991,26	€ 695.005,22	3,93
Museum of the Future	Case Study	Building	€ 204.229.663,11	€ 1.719.578,26	€ 1.504.000,00	1,14
IKEA Project	Case Study	Building	€ 40.000.000,00	€ 1.014.839,48	€ 503.642,52	2,01
BAS	Case Study	Building	£ 28.783.627,00	£ 463.750,00	€ 157.650,00	2,94
Sir Bani Yas	Validation	Marine	€ 25.000.000,00	€ 24.244,10	€ 18.656,73	1,29

The Table 5 cited above shows in summary the most important details of each project. On the last column, the B/C ratio of each project is presented. The B/C ratio of the project in Sir Bani Yas is equal to 1,29. This percentage is relatively low but not the lowest among the rest of the Case Studies. Also, it is not relatively low considering that the project is still in progress and is expected to generate more profits until the Execution phase is completed. This remark in combination with the multiple benefits quantified on Fig. 33, confirm that the total benefit of this project is high.

All the above, help the researcher validate the accurate functionality of the Framework. The reasoning behind the Framework is to enable the user record all the useful information and thus, quantify precisely the costs and benefits. Indeed, the fact that the B/C ratio is still low but close to the rest of the projects, which are completed, validates the usage of the method. Particularly, the B/C ratio demonstrates that the BIM team was able to quantify more benefits now, that the project is still in progress comparing to the rest of the Cases. Finally, if the Framework is used until the end of the Execution, more benefits will be gained and quantified and the B/C ratio might end up higher than the rest of the projects. In this case, the functionality of the method will be fully verified as it means that all or most of the benefits are assigned a monetary value.

6.3 Validation with experts

Following the quantitative part, a validation with experts was achieved. This qualitative part is of high importance as it confirms the soundness of the Framework and its applicability in other projects. Also, it includes suggestions for further improvement by people who possess long experience as well as relevant knowledge and can judge the functionality of the Framework objectively.

In order to validate the aspects of the Framework, the researcher arranged a discussion with 4 people working in the Royal BAM Group who were not involved in the Case Studies previously studied. These experts have different disciplines and are Digital Construction Program Manager, Digital Construction Managers and Planning Engineer. These people were initially introduced to the existing gaps that the Framework aims to fill, to the way this standard method works as well as the results it generates. Following, they were requested to fill individually a short survey, which is given on Appendix G, created by the researcher in order to for the researcher to integrate their opinions into the research but also acknowledge their suggestions for improvement. The responses varied as the experts agreed on some parts, disagreed on others and emphasised on multiple points for improvement.

Overall, all the experts expressed their interest in the whole concept of the proposed method. Moreover, they agreed that the framework is well-structured, the benefits are relevant to site conditions and the metrics are realistic. Following, a few suggestions were made. Firstly, the current method was characterised as subjective regarding the person who gives the number of hours spent with and without BIM applications. Therefore, a recommendation to deal with this subjectivity would be to gauge some results from previous studies and then ensure the accuracy with the given numbers. If the numbers were not close, then the interviewees would have to check the values and give more accurate results. Moreover, an additional tab that would include the benefits of BIM from the side of the interviewees would be useful rather than just asking the outcome. This would help capture more benefits. Furthermore, another recommendation would be to divide the benefits into the multiple parts of the life-cycle of the project. Also, it was suggested that incorporating the value from the change of orders and risks would help. One of the most important suggestions that were made both from an expert but also during the application in the current project, was to integrate the cost of reworks that is saved. This is considered remarkable because it involves cost of equipment, fuel consumption, idle time and valuable time of engineers. Finally, a part covering health & safety aspects would also be useful.

Consequently, experts were asked to assess the soundness of the Framework. Their response was that the framework is simple to implement because most part of it is self-explanatory, there is not an issue with its usage and the benefits it includes are those which they indeed are identified in real projects. Regarding the way B/C ratio is calculated, they characterised it as accurate as long as double counting is avoided. This depends mainly on the expertise of the user. A suggestion for further improvement would be to measure the efficiency of the whole process.

The next question had to do with the applicability of the Framework in other construction projects. All the experts agreed that the Framework is applicable and they intend to use it in a Workshop arranged by BAM Nuttall. This Workshop aims to capture the ROI of BIM Implementation on a specific project. In fact, one of the experts highlighted that this Framework was preferred to other similar because of its reliability and easy understanding. Some slight corrections would refer to the descriptions of the benefits as they are considered more academical. However, people on the construction site are not comfortable with them and this would not facilitate the record of data and the benefits gained.

Following, experts were asked in which way could this Framework be adopted by a company and if special organizational or managerial adjustments should be made. Two of them agreed that this Framework would be adopted by the DC department along with the help of the Project Manager or Contracts Manager. Also, they suggested that some planning and adjustments regarding the uses of BIM could bring massive improvements to the method.

Finally, experts were asked which impact could this Framework have on the BIM strategy of a company. All of them agreed that the impact would be huge. To be more precise, the first expert claimed that by showing the value of the return, they would get more interest from the clients who believe the BIM is time-consuming and expensive. Considering that this is the main problem currently and this Framework would make more people positive to apply BIM on their project. Moreover, another expert believes that the use of the framework provides useful data. This data could further identify the current gaps in the deployment of the technology. Consequently, these gaps would highlight the key value areas that can update the strategic decision making. Furthermore, it was said that understanding where the greatest return on investment arises will have an effect on where DC resources are applied. Lastly, the fourth expert believes that every strategy needs a business case and this is the aim of this Framework. In fact, ROI is the most important objective and normally strategies are built according to it. Hence, if a significant ROI is provided, companies will invest more on Research & Development and BIM resources and would also digitize traditional their processes.

6.4 Conclusion

The validation constitutes a part of the research which is of significant importance. The purpose of this chapter was to verify that the proposed Framework can indeed represent an accurate evaluative method for BIM implementation. This verification was both quantitative and qualitative. The quantitative part involved the application of the method in a project which is still in progress whereas the qualitative part included a short discussion with experts in order to introduce them in the concept of the Framework, followed by a short survey which was answered independently and objectively. Hence, when the validation was completed, the researcher could answer the Sub-question 6 which is the following.

Sub-question 6: *To what extent can an evaluation of BIM into construction projects be standardised?*

The first way to clarify the extent to which the evaluation can be standardised was the application in a pilot project. The difference of the Case Studies was that chapter 4 involved only ex-post evaluation since the projects were all completely or almost finished. In contrast, the application in a pilot project enables the researcher record all the essential information and quantify accurately the positive and negative costs so far. The results of this application indicate that the Cost of Personnel is again the highest of the 3 reaching so far 59,26% of the Total BIM Costs. Eventually, the ratio, so far, is 1,29 which is within the range of the ratios of the Case Studies.

The comments that are received from the experts that used this Framework constitute the validation of it. Thus, these comments in combination with the outcome of the discussion with experts that follows on section 6.3, indicate the way that this evaluation can be standardised.

According to the experts, an evaluation of costs and benefits and specifically this proposed Framework can potentially be applicable in any construction project. The points of the improvement they suggest include some advice as to how it could be more accurate in order to reflect the real conditions. To be more precise, the inclusion of the cost of the rework that is avoided is suggested both during the pilot and later during the discussion. In addition, the ensuring of the soundness of the results according to previous studies is suggested. Moreover, a simpler description of the benefits is recommended as the current one is considered more academical. In addition, the division of the benefits into the multiple stages of the life-cycle of the project is also recommended.

To conclude, except for the recommendations that were analysed briefly in the previous paragraph, all of the experts agree that the specific evaluative method can be applicable in any construction project as it is self-explanatory and easy to understand and use by the reader. Furthermore, the experts state that the costs and benefits it includes are totally identified in real-life projects. As an outcome, an evaluation of costs and benefits of BIM can be potentially standardised if small points of improvement are achieved.

7. Conclusions, Discussion & Recommendations

7.1 Research Questions

The Research Questions were formed by the researcher as one of the initial steps which motivated the present study. The objective of them is to help the researcher attain gradually her goal; the fill of the research gap. Hence, the purpose of the Main Research Question is to indicate the research gap and at the same time, trigger the interest of the reader. The Sub-questions constitute the stepping stones which lead to the Main Questions. Therefore, all of them have been answered through the progress of the research. In this part, the researcher will answer briefly the 6 Sub-questions in order to reach eventually the answer to the Main Research Question.

***1. Which are the costs and benefits associated to BIM implementation*?**

According to the published literature, the costs of BIM implementation can be either direct and include the cost of software, hardware and installation costs or indirect and involve organisational and human costs. The direct costs are associated with the implementation and operation of BIM while the indirect concern the adoption of it. These costs mainly refer to the steps which are required in order to integrate this technology within the operational context of a company and therefore, require some investments from the side of the contractor.

Regarding the benefits, these can be either tangible and quantifiable or have an abstract nature which is hard to be captured and, thus, quantified. The benefits of BIM implementation are acquired by the usage of the 3D Model and 4D Model. Firstly, the main benefits that are associated to 3D Model include the Visualisation, Improved Collaboration, QTO, Waste Reduction, Clash Detection, Federation of the model, Coordination, As-built Drawings, Cost Estimation and CDE. Additionally, the benefits that are generated from the application of the 4D Planning are the following; Sequencing, Monitoring, Constructability and Visualisation.

2. Which unique characteristics of BIM (in comparison to traditional 2D methods) warrant an evaluation into its added value?

The SWOT Analyses on traditional methods and BIM on section 2.3 present the characteristics of each methodology. The purpose of the SWOTs was to clarify the differences between these methodologies and help the reader understand reasonably why the evaluation of costs and benefits of BIM is desired. When the SWOT Analysis for BIM was completed, the researcher could point-out the characteristics of BIM that cause the need for an evaluation. Particularly, the following special characteristics of BIM in comparison to 2D traditional methods amplified the need for evaluation.

Firstly, the Strengths that are presented on Fig. 7 and include the Efficient on-site Supervision, Improved Collaboration, Accurate Cost Estimation and Take-off, Enhanced Documentation as well as the Prestige of the Company, constitute the most significant benefits that BIM methods offer and motivate further investigation. Additionally, the first Weakness that is mentioned and involves the High Cost of Implementation motivates the reader to dive into BIM costs and evaluate them in comparison to BIM benefits. Nevertheless, it should be admitted that the most important characteristics of BIM that warrant the evaluation are the Threats. Particularly, the Reluctance of the

Stakeholders, the Unfamiliarity with BIM and the Lack of exact substantiation of the profits constitute the Threats that the evaluation method aims to encounter. The main purpose is to evaluate the costs and benefits and thus, raise awareness regarding BIM methods.

3. How can the costs and benefits associated to the implementation of BIM be effectively substantiated?

The effective substantiation of costs and benefits is proven challenging and complex. The main barrier is the lack of sufficient knowledge and information regarding BIM implementation. This lack requires to personal assumptions and testimonies in order to track the costs and benefits of BIM which, consequently, leads to inaccurate results.

This quantification can be effectively implemented and consists of a few steps. These steps involve the constant and detailed record basis of important data and whatever happens on site and has to do with BIM. These events would happen because of BIM usage and would either reduce the duration of the activities, reduce the waste or would offer added value to the services. The reduction of the duration and waste is directly connected with saving of cost. Therefore, the benefits would be assigned a specific monetary value. Apart from the benefits, the Project Team would also record all the costs of BIM which involve the cost of software, hardware and human resources.

The cost of software would be measured based on the cost of the licenses that are used. Following, the cost of hardware involves the money required to buy the technological equipment that would support BIM applications. Last, the cost of personnel refers to the salary of the members of the BIM team.

The proposed Framework can potentially deal with these challenge as it provides standard guidelines which aim to record all the important data and thus make the calculation more accurate.

4. Which information is required in order to assign monetary value to the tangible benefits of BIM?

Indeed, the substantiation of the benefits was the most challenging part of the evaluation procedure. As explained on section 3.3.2, the two possible ways to calculate their monetary value would be based on the saving of cost or the added value of BIM. Particularly, the saving of cost is caused either by the saving of time or by the reduction of waste. Regarding the saving of time, the duration of an activity with and without BIM was required. Then, the difference of these two durations is multiplied with the wage (per hr/day/month) of the staff. This number is the saving of cost for the specific activity due to BIM. With regards to the reduction of waste, the quantities of materials calculated with and without BIM applications were also quantified. Following, the difference of these two quantities was multiplied with the price of the specific material (per $m/m^2/m^3$). This number is the saving of cost due to the reduction of waste. Finally, the added value could be quantified either by the price of BIM on the BOQ which is a cost for the client but a profit for the contractor or by the additional value that BIM offered by enhancing a particular part of the whole performance of the contractor.

5. In which way do the costs & benefits of BIM implementation inform on the impact of BIM strategies of the Contractor?

The result of cost and benefit substantiation is the B/C ratio which on the Case Studies ranges from 1 to 8. The analysis of the results indicates that the cost of personnel is remarkably higher than the rest two types of costs and ranges from 83,5%-97,5% of the Total Cost of BIM while the cost of software ranges from 0,8% to 3,55% and this of the hardware from 1,19% to 2,56%. The reasons that can possibly cause this high cost of human resources were stated and involve either the low level of BIM education, the difficulty of the project itself or the lack of expertise. Regarding the benefits, their analysis shows that, so far, the usage of 3D model has generated the highest benefits in 3 of the 5 cases while the 4D model and specifically the Interface Coordination which produced the highest benefit in Moín, significantly beneficial.

Moreover, the Cost of Personnel is confirmed as the most sensitive variable. Hence, this constitutes the area that the contractor should focus his attention. The establishment of BIM Standards and the focus on Critical Activities of the project are suggested as two methods to integrate into the BIM strategies of the contractor. Firstly, the BIM standard procedures and protocols could ideally save the time spent on BIM Implementation and secondly, the focus on the Critical Activities can save higher amount of money in comparison to the Non-critical ones, as proven on the first Case Study.

The proposed Framework can perhaps be adopted by the contracting company as part of the standard procedures and contribute in controlling the inputs and outputs of BIM Implementation throughout the whole Execution.

6. To what extent can an evaluation of BIM into construction projects be standardised?

The purpose of the validation is to ensure the soundness of the evaluative method proposed. The application of the Framework on a pilot project which is still in progress verifies that the Cost of Personnel is the highest of the 3 reaching so far 59,26% of the Total BIM Costs. The ratio, so far, is 1,29 which is within the range of those on the Case Studies. Therefore, these results confirm the validity of the Framework. Moreover, the comments that stem from the application in the pilot project in combination with the discussion with experts indicate the way that this evaluation be standardised.

According to the experts, an evaluation of costs and benefits and this particular Framework could potentially be applicable in any construction project. The points of the improvement involve some advice as to how it could be more accurate in order to reflect the real conditions. To be more precise, the inclusion of the cost of the rework that is avoided is suggested unanimously. In addition, the ensuring of the soundness of the results according to previous studies and published literature would help. Furthermore, a simpler description of the benefits would make the Framework more useful as the current one is more academical. In addition, the division of the benefits into the multiple stages of the life-cycle of the project can also be considered.

Nevertheless, according to the experts, this Framework can be applicable in any construction project as it is self-explanatory and easy to understand and to use by the reader. In addition, the costs and benefits it includes are totally identified in real-life projects. As an outcome, an evaluation of costs and benefits of BIM can be potentially standardised if small points of improvement are achieved.

Main Research Question

What could constitute a standard method of evaluating the costs and benefits of BIM in Construction Projects?

The answer to the Main Question, which motivated the present research, stems gradually from all the answers given above. Ideally, this standard method would be applied by the Project Team from the beginning of the Execution phase as shown on Fig. 35. The inputs of this procedure are the BIM workflows (3D model, 4D model, 5D model & Site data capture) and the 3 different types of costs (cost of software, hardware and personnel. Moreover, all the important information regarding BIM usage on the construction site, would be recorded on time and on a regular basis either daily, weekly or monthly depending on the conditions of the project and its complexity. Lessons learnt sessions would assist in capturing the essential data. Following, the transparent quantification of costs and benefits would be implemented with the use of simple formulas. The result of this quantification is the CBA and particularly the B/C ratio which represents the amount of money gained from the contractor, for every unit of money invested on BIM. CBA is considered the most appropriate method as it allows the particular evaluation of the inputs and outputs of the Framework. Hence, the Contractor can define the Highest Cost, namely the Cost of Personnel as well as the Highest Benefits and structure his BIM strategies accordingly. For instance, he can establish standard procedures aiming to control the long working manhours and he can focus on the critical activities which, provably, give higher benefits. This evaluative procedure would be constantly updated during the Execution phase as more information and data is recorded regularly and B/C ratio can be calculated anytime of the process. This gives the Contractor a sufficient insight and he is able to monitor more efficiently the implementation and keep the costs within the desired limits. As a result, the evaluation would raise awareness within AEC industry not only about the costs and benefits associated with BIM but also the impact that these have on BIM strategies in order to enhance their performance during the project but in the future as well.

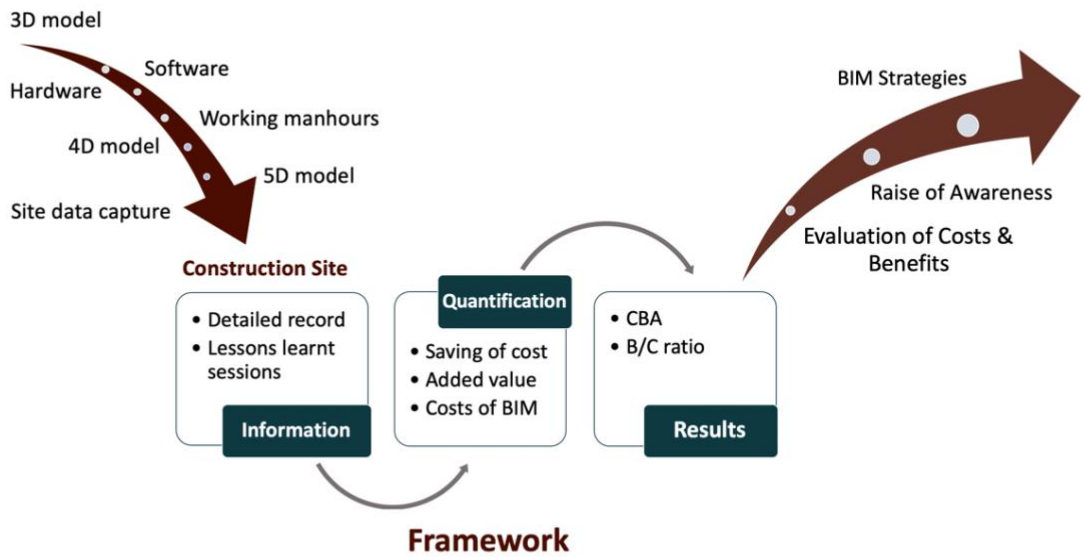

Figure 35 Evaluative Method proposed

7.2 Discussion

In this part the implications of the research both for Academia and AEC industry are presented. Also, the limitations of the research are mentioned. In this way, the researcher intends to communicate the connotation of her research after the analysis presented in the report.

7.2.1 Framework for the Academia

Considering the problem statement that was initially discovered and clarified, the present research aims to offer a valuable piece in the Academia. Firstly, the gap in the existing evaluating tools was identified alongside with the barriers that cause this lack. Based on the theoretical concept as well as the examination of the 5 Case Studies, the most important barrier that creates this gap is the the insufficient relevant information provided. This lack leads to calculations which are not clearly defined by the researchers and understood by the readers. Hence, the most important shortcoming of this problem is the unawareness of the costs and benefits of BIM implementation.

This shortcoming does not facilitate the adoption of BIM methodologies. Considering the relatively recent introduction of BIM, the education of people around this topic is suggested. Nevertheless, when the evaluative procedures and measurement tools are not easily understood by people interested on this topic, the adoption of BIM applications is not encouraged. Therefore, the objective of this research, the proposal of a transparent and comprehensive method, intends to potentially fill this gap. In this way, barriers such as the insufficient information and data would be possibly eliminated. Besides, this tool would attempt to offer a clearer definition of inputs and outputs as well as calculations. As a result, readers would be encouraged to understand the source of each input and output and familiarise more themselves with BIM implementation. Consequently, people would ideally be more aware of costs and benefits and thus, BIM adoption would be potentially encouraged.

7.2.2 Framework for the Industry

Apart from the scientific contribution, this research strives to offer valuable results to the AEC industry as well. The lack of a transparent measurement and evaluative tool does not encourage the establishment of BIM methodologies in the industry. On the one hand, contracting companies need to be up-to-date and offer competitive products to their clients. On the other, they are not totally aware of the valuable benefits that BIM can offer and are prejudiced because of the high cost of implementation. As a result, they tend to be reluctant towards this innovative technological methodology.

The establishment of BIM standards and protocols within companies and more widely within AEC industry would definitely promote BIM implementation. People working in the industry would acquire the necessary education and knowledge and would gradually gain expertise. Therefore, applications would be used efficiently when needed and contracting companies would get beneficial results. Part of these standard procedures could be the proposed Framework. This Framework would capture all the important data which are now not recorded on time and, eventually, quantify accurately costs and benefits. In this way, the contractor would be sufficiently aware of the progress, would monitor the positive and negative costs required for BIM and would be able to optimize BIM implementation in future projects.

7.2.3 Limitations of the research

The present research possesses some limitations which should be acknowledge by the readers in order to further use or develop the findings of this study. It should be mentioned that most of the limitations are caused because of the limited time that was available for the research. The limitations that will be analysed are the following.

- Comparison of B/C among the projects

As mentioned in the 2nd chapter of this report, the CBA method is mainly used in order to make comparisons among alternative choices. However, the research that was carried out did not allow comparisons among projects. Due to the limited amount of time available, the Case Studies that were investigated did not possess many similarities. Therefore, a direct comparison between projects of the same type, size or value was not possible. If projects had very similar characteristics then a comparison based on their B/C would be feasible. This procedure would add value in the research. Particularly, it would provide a better understanding of the variables that have an impact on the final result and the costs and benefits that are expected in each type of project. Moreover, it would enable the researcher define the reasons that led to the specific ratio and suggest improvements for further improvement.

- Comparison between traditional methods and BIM

Apart from the comparison described above, a comparison between projects of the same characteristics that were executed with the use of traditional methods and BIM, would also be valuable. This comparison would directly indicate the impact, either positive or negative, that BIM applications have on the implementation of construction projects. Moreover, it would allow the audience evaluate BIM Implementation and understand the benefits and flaws of each technique. However, this comparison was not achieved because of two reasons. Firstly, the limited time available restricted the area of study to investigation of projects that involved BIM applications. Secondly, it was not possible find enough information on projects of the same characteristics that were carried out using conventional methods and BIM. This lack of data would cause additional estimations and judgements and the result would not be highly accurate.

- Quantification of benefits

As mentioned, the lack of information available makes assumptios and personal judjements necessary. Given that the Cases studied were either completely or almost finished, only an ex-post evaluation was feasible. Therefore, interviewees were required to go back in time and track data that was recorded during the execution phase of the project such as reports, BOQs, etc. Nevertheless, when this information was not available or enough for the quantification of costs and benefits, assumptions had to be made. Moreover, assumptions were required in order to estimate the situation without BIM. For example, in a project where BIM was used from the start, it was not easy estimate the time delay that would have been caused if a specific clash was not detected on time. Hence, Project Managers, Construction Managers and BIM Engineers were required to make some personal estimations based on their knowledge and experience of previous similar projects. It should be mentioned that all the estimations were made in a conservative way in order to produce conservative results. This lack of available data constituted a limitation on the procedure of the quantification and the final results because it was not possible to depict utterly the actual situation.

- Addition of more benefits

The limited time available was the barrier that mainly caused the limitations in this research. In order to form the Framework and conclude to the list of benefits that would be included, the researcher conducted an extensive literature research and some rounds of interviews with experts. The benefits that she considered were added on the list according to previous research and the discussions. However, it is understood that if more time was available, more Case Studies would be examined. Subsequently, a few more rare and uncommon benefits would be explored and added to the list. Thus, it becomes clear that as more projects are studied, more benefits and barriers regarding BIM would stem and would be included in the present research.

7.3 Recommendations

The limitations analysed above lead to several recommendations both for the scientific field and BAM International. With regards to Academia, these recommendations will lead to further research and consequently a more thorough insight from theoretical perspective. Regarding to BAM International, this section will help the company improve its strategies relevant to BIM Implementation and thus, enhance their performance.

7.3.1 Recommendations for Future Research

Regarding the Academia, there is a couple of recommendations and ideas for future studies. Firstly, an examination of more Case Studies would be suggested. This examination aims to expand the number of benefits that can be gained by the contractor. This can be achieved only if multiple projects are studied considering that each execution constitutes a unique case with different conditions. Apart from the benefits, this extensive exploration can provide additional information regarding the costs that should be considered and even quantify some indirect costs such as the organisational and human costs. Moreover, a suggestion for further research that would bring valuable findings is the comparison between 2D traditional methods and BIM. As shown in SWOT analyses, these two techniques both involve advantages and drawbacks. Therefore, the extensive examination of similar projects carried out with a different approach would enable the comparison of these two techniques. The result that would stem from the comparison would show which methodology is more beneficial, would evaluate BIM applications and would indicate the points of improvement. Finally, it is suggested that future research could possibly focus on the Cost of Personnel. Considering that this input constitutes the significantly higher cost than the other two, AEC firms should develop tools to evaluate if the time spent on BIM Implementation is spent in the optimal way. Hence, they would be able to control the working hours and monitor, consequently, the Cost of Personnel.

7.3.2 Recommendations for BAM International

With respect to AEC industry and especially BAM International, a few recommendations for future improvement are given. Primarily, the application of the Framework on other projects would provide valuable insight and maybe, enable comparisons among the projects based on the B/C ratio. This would facilitate the contractor acknowledge the areas of attention and, in this way, try to attain higher profits in future projects. Moreover, a comparison between 2D and 3D methods would clarify the type of the projects and the conditions that each methodology is more suitable and beneficial. Thus, he would gain knowledge and become more able to judge objectively in order to employ BIM applications when it would indeed be necessary and profitable. Eventually, as already mentioned the adoption of BIM standards could potentially enhance their improvement. The proposed Framework can probably be included in the standardised procedures. Precisely, it would ideally facilitate the recording of all the important information. In this way, the firm could potentially not only quantify numerous tangible and intangible benefits but additionally, develop their services regarding BIM. The record of data, the hold of lessons learnt among Project Teams and the accurately quantification of costs and benefits either direct or indirect, would optimally help the contractor know his abilities and incapacities and improve their performance accordingly. Finally, it is recommended that the company finds a tool in order to measure the quality time that is spent on BIM applications and in this way, perhaps, reduce the long working hours. This measure in combination with the Framework which quantifies all the inputs and outputs would help the contractor keep an efficient track of the money that is being spent and gained during the project and ensure that they always remain within the desired budget.

8. Reflection

This thesis project is the last part of my academic studies in Civil Engineering and Construction Management and Engineering. This long journey developed my skills but also enhanced my personal characteristics. The specific research elaborated on my particular interest in BIM and the position it possesses in the AEC industry. I was firstly introduced to the concept of BIM during my undergraduate studies. This first contact was enough to trigger my interest in this innovative philosophy. Soon I was extremely impressed with its effective impact on the management of a project. Consequently, I desired to work more on it and thus, I proposed it in my motivation letter for my entry in TU Delft, as my first desired thesis topic. Therefore, I sought for a project relevant to BIM Implementation. BAM International gave me the opportunity to carry out a research on a highly motivating and practical topic regarding the costs and benefits of BIM application in construction projects. The results of my research totally rewarded my efforts and satisfied my initial desire to dive into BIM philosophy.

The first part of the thesis involved a thorough literature review in order to define precisely the research gap and form a scientific approach. When I had acquired the theoretical background of BIM methodologies, I started interacting with experts within the company. These interactions ensured me about the need of BIM evaluation. Therefore, the objective was to develop a standard procedure, applicable in any project, which would record the essential information, quantify the costs and benefits and, eventually, evaluate BIM implementation. My driving force was the interest that these people showed in the enhancement of their performance regarding BIM through the establishment of standard procedures. The multiple rounds of discussions not only helped me structure the method but also provided me with a thorough insight of BIM application in construction projects. Following, in collaboration with the experts, I quantified the costs and tangible benefits of BIM and made efforts to assign monetary values to the intangible ones. This procedure was challenging due to the limited time that all of us had as well as the lack of relevant information. Eventually, the Framework was efficiently applied on construction projects and the ratio was calculated. This application on Case Studies indicated that the Framework is functional, easy to use and if used from the initiation of the Execution phase, can capture the information needed. Following, the results of the Case Studies offered valuable knowledge and indicated that the cost of personnel is significantly higher than the other two costs of BIM. In this part, I understood clearly the impact that the results can have on the BIM strategies of the contractors such as the need to control the cost of personnel in future projects. Therefore, I concluded that the establishment of BIM standard procedures, potentially including the proposed Framework, would contribute positively in the performance of the contractors. Eventually, the validation part verified the soundness of the model I developed and in combination with the feedback that I received from experts with experience in the AEC industry can potentially encourage the applicability of the Framework in future projects.

Overall, this research indicated to me the value of BIM applications in construction projects, and the lack of awareness concerning this value. In addition, I realised the need of the establishment of standard procedures and protocols regarding BIM within the company and the adaption of an evaluative method in order to capture on-the-spot the required data which would potentially substantiate the intangible benefits as well. Finally, I concluded that the value of my research is that the proposed method would potentially enable the contractor monitor the costs that he is required to provide and the benefits that he gains, on real time. Hence, he would be able to manage efficiently the whole BIM implementation and strive for as highly beneficial results as possible.

BIBLIOGRAPHY

Ahankoob, A., Khoshnava, S. M., Rostami, R., & Preece, C. (2012). BIM Perspectives on Construction Waste Reduction. *Management in Construction Research Association* (pp. 195-199). Kuala Lumpur: UTM RAZAK School of Engineering and Advanced Technology .

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

Azhar, S., Khalfan, M., & Maqsood, T. (2012). Building Information Modeling (BIM): Now and Beyond. *Australasian Journal of Construction Economics and Building*.

BAM International Projects. (2020, September). Opgehaald van BAM International: https://www.baminternational.com/en/projects

Barlish, K., & Sullivan, K. (2012). How to measure the benefits of BIM — A case study approach. *Automation in Construction*, 149-159.

Bertin, I. (2019). Construction, deconstruction, reuse of the structural elements: the circular economy to reach zero carbon. *IOP Conference Series Earth and Environmental Science ·*. Graz: IOP Publishing.

Bryde, D., Broquetas, M., & Volm, M. J. (2013). The project benefits of Building Information Modelling (BIM). *International Journal of Project Management*, 971–980.

Charef, R., Alaka, H., & Emmitt, S. (2018). Beyond the third dimension of BIM: A systematic review of literature andassessment of professional views. *Journal of Building Engineering*, 242-257.

Chin, R., & Lee, Y. B. (2008). Analysis of Data. In *Principles and Practice of Clinical Trial Medicine* (p. 348). Academic Press.

Ciribini, A., Mastrolembo Ventura, S., & Paneroni, M. (2016). Implementation of an interoperable process to optimise design and construction phases of a residential building: A BIM Pilot Project. *Automation in Construction* , 62-73.

Clayton, M. J., Johnson, R. E., Song, Y., & Al-Qawasmi, J. (1998). *Information Content As-built Drawings.* Texas: CRS Center, College of Architecture, A&E University.

Czmoch, I., & Pekala, A. (2014). Traditional design versus BIM based design. *Procedia Engineering* , 210-215.

Diaz, P. M. (2016). Analysis of Benefits, Advantages and Challenges of Building Information Modelling in Construction Industry. *Journal of Advances in Civil Engineering*, 1-11.

Eastman, C., Teicholz, P., Sacks, R., & Liston, K. (2008). *BIM Handbook.* Hoboken: John Wiley & Sons, Inc.

Giel, B. K., & Issa, R. R. (2013). Return on Investment Analysis of Using Building Information Modeling in Construction. *Journal of Computing in Civil Engineering*, 511-521.

Giel, B., & Issa, R. R. (2011). BIM Return on Investment: A Case Study. *Journal of Building Information Modeling*, 24-27.

Hadzaman, N. A., Takim, R., & Hadi Nawawi, A. (2015). Building Information Modelling (BIM): the impact of project attributes towards clients' demand in BIM-based project. *WIT Transactions on The Built Environment*, 59-69.

Hardi, J., & Pittard, S. (2015). If BIM is the solution, what is the problem? A review of the benefits, challenges and key drivers in BIM implementation within the UK construction industry. *Journal of Building Survey, Appraisal & Valuation*, 366-373.

Hardin, B. (2009). *BIM and Construction Management.* Indianapolis: Wiley Publishing, Inc.

Hardin, B., & McCool, D. (2015). *BIM and Construction Management; Proven Tools, Methods, and Workflows.* Indianapolis: John Wiley & Sons, Inc.

Hergunsel, M. (2011). *Benefits of Building Information Modeling for Construction Managers and BIM based Scheduling.* Worcester : Digital WPI.

Hwang, K. (2016). Cost-benefit analysis: its usage and critiques. *Journal of Public Affairs*, 75–80.

Jones, T. (2006, November 19). Cost and Benefit Analysis vs. Return on Investment. *HealthManagement.org*.

Jupp, R. J. (2013). BIM investment: understanding value, return and models of assessment. *The 38th Australasian Universities of Building Education Association Conference.* University of Auckland.

Koutamanis, A. (2020). Dimensionality in BIM: Why BIM cannot have more than four dimensions? *Automation in Construction*.

Lee, D.-G., Park, J.-Y., & Song, S.-H. (2018). BIM-Based Construction Information Management Framework for Site Information Management. *Advances in Civil Engineering*.

Level of Development Specification Part I. (2019, April). Opgehaald van BIM FORUM: https://bimforum.org/resources/Documents/BIMForum_LOD_2019_reprint.pdf

Li, J., Hou, L., Wang, X., Wang, J., Guo, J., Zhang, S., & Jiao, Y. (2014). A Project-based Quantification of BIM Benefits. *International Journal of Advanced Robotic Systems*.

Lindblad, H., & Rudolphsson Guerrero, J. (2020). Client's role in promoting BIM implementation and innovation in construction. *Construction Management and Economics*.

Liu, L., Stumpf, A., Kim, S., & Zbinden, F. (1994). Capturing as-built project information for facility management. *Computing in Civil Engineering* (pp. 614-621). Washington, DC: Proceedings of the 1st Congress on Computing in Civil Engineering. Part 1.

Liu, Z., Lu, Y., & Chang Peh, L. (2019). A Review and Scientometric Analysis of Global Building Information Modeling (BIM) Research in the Architecture, Engineering and Construction (AEC) Industry. *Buildings*.

Liu, Z., Osmani, M., Demian, P., & Baldwin, A. N. (2011). The potential use of BIM to aid construction waste minimisation. *Proceedings of the CIB W78-W102 2011: International Conference.* Sophia Antipolis: Centre Scientifique et Technique du Bˆatiment (CSTB).

Lopez, R., Chong, H.-Y., Wang, X., & Graham, J. (2016). Technical Review: Analysis and Appraisal of Four-Dimensional Building Information Modeling Usability in Construction and Engineering Projects. *Journal of Construction, Engineering and Management*, 1.

Love, E. P., Simpson, I., Hill, A., & Standing, C. (2013). From Justification to Evaluation: Building Information Modeling for asset owners. *Automation in Construction*, 208-216.

Lu, W., Fung, A., Peng, Y., Liang, C., & Rowlinson, S. (2014). Cost-benefit analysis of Building Information Modeling implementation in building projects through demystification of time-effort distribution curves. *Building and Environment*, 317-327.

Manning, R., & Messner, J. I. (2008). CASE STUDIES IN BIM IMPLEMENTATION FOR PROGRAMMING OF HEALTHCARE FACILITIES. *ITcon*, 446.

McGraw Hill Construction. (2014). *The Business Value of BIM for Construction in Major Global Markets: How Contractors Around the World Are Driving Innovation With Building Information Modeling.* McGraw Hill Financial.

Migilinskas, D., Pavlovskis, M., Urba, I., & Zigmund, V. (2017). Analysis of problems, consequences and solutions for BIM application in reconstruction projects . *Journal of Civil Engineering and Management* , 1082-1090.

Migilinskas, D., Popov, V., Juocevicius, V., & Ustinovichius, L. (2013). The Benefits, Obstacles and Problems of Practical Bim Implementation. *11th International Conference on Modern Building Materials, Structures and Techniques, MBMST* (pp. 767-774). Vilnius: Elsevier Ltd.

Mitchell, D. (2012). 5D BIM: Creating Cost Certainty and Better Buildings. *2012 RICS Cobra.* Las Vegas, Nevada, USA.

Mouter, N. (2014). *Cost-Benefit Analysis in Practice.* Delft: Delft University of Technology.

Neelamkavil, J., & Ahamed, S. S. (2012, February 1). *The Return on Investment from BIM-driven Projects in Construction.* Opgehaald van National Research Council of Canada: https://nrc-publications.canada.ca/eng/view/object/?id=af0db2c8-8d85-4e26-b584-f51ae0fa9eb5

Nepal, M., Jupp, J., & Aibinu, A. (2014). Evaluations of BIM: Frameworks and Perspectives. *International Conference on Computing in Civil and Building Engineering.* Orlando, Florida: American Society of Civil Engineers.

Olsen, D., & Taylor, J. M. (2017). Quantity Take-Off Using Building Information Modeling (BIM), and Its Limiting Factors. *Creative Construction Conference 2017.* Primošten: Procedia Engineering.

Qian, A. Y. (2012). *Benefits and ROI of BIM for Multi-Disciplinary Project Management.* Singapore.

Rowlinson, S., Collins, R., Tuuli, M. M., & Jia, Y. (2009). Implementation of Building Information Modeling (BIM) in Construction: A Comparative Case Study. *Proceedings of the 2nd International Symposium on Computational Mechanics and the 12th International Conference on the Enhancement and Promotion of Computational Methods in Engineering and Science,*, (pp. 572-577). Hong Kong & Macao.

Russell, A., Staub-French, S., Tran, N., & Wong, W. (2009). Visualizing high-rise building construction strategies using linear scheduling and 4D CAD. *Automation in Construction* , 219-236.

Sacks, R., Gurevich, U., & Shrestha, P. (2016). A REVIEW OF BUILDING INFORMATION MODELING PROTOCOLS, GUIDES AND STANDARDS FOR LARGE CONSTRUCTION CLIENTS. *Journal of Information Technology in Construction*, 479.

Salciccioli, D. J., Crutain, Y., Komorowski, M., & Marshall, C. D. (2016). Sensitivity Analysis and Model Validation. In *Secondary Analysis of Electronic Health Records* (pp. 265-166). MIT Critical Data.

Sammut-Bonnici, T., & Galea, D. (2014). SWOT Analysis. In L. C. Cooper, *Wiley Encyclopedia of Management.* John Wiley & Sons, Ltd.

Shin, M., Lee, H., & Kim, H. (2018). Benefit-Cost Analysis of Building Information Modeling (BIM) in a Railway Site. *Sustainability*.

Sid, A. (2020). *Advantages and disadvantages of traditional and lean method.* Sydney: 49002 Managing Projects.

Silverio, A., Suresh, S., Renukkapa, S., & Heesom, D. (2016). BIM education framework for clients and professionals of the construction industry. *1st International UK BIM Academic Forum Conference.* Glasgow.

Tauriainen, M. K., Puttonen, J., & Saari, A. (2015). The assessment of constructibility: BIM cases. *Electronic Journal of Information Technology in Construction ·*, 51.

Thurairajah, N., & Goucher, D. (2013). Advantages and Challenges of Using BIM: a Cost Consultant's Perspective. *49th ASC Annual International Conference Proceedings.* Associated Schools of Construction.

Turk, Z. (2016). Ten questions concerning building information modelling. *Building and Environment*, 274-284.

Varghese, P. (2019). *Influence and Adoption of BIM within the AEC Industry.* Delft: Bouwkunde, Technische Universiteit Delft.

Walaseka, D., & Barszcz, A. (2017). Analysis of the adoption rate of Building Information Modeling [BIM] and its Return on Investment [ROI]. *Procedia Engineering*, 1227-1234.

Zima, K., Plebankiewicz, E., & Wieczorek, D. (2020). A SWOT Analysis of the Use of BIM Technology in the Polish Construction Industry. *Buildings*.

APPENDIX A

TABLE OF QUANTIFICATION OF APM TERMINAL IN MOIN – COSTA RICA

Sequence Number	Workflow	Code	Category	Definition of Benefits	Project (APM Terminal)	Tangible/Intangible	Quantifiable with; saving of time, reduction of waste, added value	Duration with BIM (hrs) (Tn)	Duration without BIM (hrs) (Tt)	Required Resources (number of people)	Saving of time (Δt*Required Resources)	Materials with BIM (Qn)	Materials without BIM (Qt)	Added Contract Value	Literature Reference	Cost Saving	Additional Information
1	3D Permanent Model																
		1.1	Requests for Information	Requests for Information are issued if conflicts among the elements are detected of if there are defficiencies. When these conflicts are solved on-time, time is saved during the construction phase.	Yes	Intangible									40% elimination of unbudgeted change		
		1.2	Visualization of Risks and Opportunities	The degree to which the visualization of Permanent Works within a 3D model aids in visualizing either risks and/or opportunities.	Yes	Intangible											
		1.3	Clash Detection & Design Changes	Clashes among the Architectural, Structural and MEP works can be deteted. Once they are detected, changes in design can be made and the 3D model is updated automatically. This leads to prevention of future mistakes.	Yes	Intangible									10% of the contract value		
		1.4	As-Built Drawings	During project execution the 3D model is constantly updated according to the changes. At the end of the project, the as-built model conditions are defined and as-built drawings can be extracted easily.	Yes	Tangible	Saving of time	0	1299	7 crews of 2 people	5					245000	
		1.5	Coordination of utilities	Especially in large and complex projects which involve numerous activities, the coordination of the interfaces is essential in order to avoid confusion on-site and time delays.	Yes	Intangible											
		1.6	Collaboration	Information sharing facilitates the communication and enhances the collaboration among the stakeholders.	Yes	Intangible									35%		
		1.7	Increased Documentation/Claims	Information is managed and used properly. In this way, the understanding of the client is increased and there is high chance of speeding-up the construction process.	Yes	Intangible											
2	3D Model for Quantity Take-off																
		2.1	Complexity of Structure (Shape)	The shape of the structure is of such complexity that it is not quantifiable without the use of a 3D model.	No												
		2.2	Efficiency of Processes (Time)	The 3D model helps in creating BOQ in a time-efficient way.	Yes	Intangible											
		2.3	Accuracy of Estimate	The 3D Model provides higher accuracy of quantity estimates than traditional methods. Consequently, errors and over-ordering are avoided and waste of materials is reduced.	Yes	Intangible											
		2.4	Variation Control	The degree to which 3D model adds value when controlling a project under uncertain conditions.	Yes	Intangible											
		2.5	Efficiency of Data Handover	The degree to which 3D model would make the data handover between the office and site more efficient.	Yes	Intangible											
3	3D Based Surveying																
		3.1	Complexity of Projects	The complexity of some projects makes the surveying hard and time-consuming.	Yes	Intangible											
		3.2	Efficiency of Data Handover	If the 3D model is directly installed on the total station, the on-site coordination is achieved faster.	Yes	Tangible	Saving of time	0,5	2		0,15					7350	
4	4D Model for Planning																
		4.1	Interface coordination	Especially in large and complex projects which involve numerous activities, the coordination of the interfaces is essential in order to avoid confusion on-site and time delays.	Yes	Tangible	Saving of time	6	10,08	4,08	4,08					2962080	
		4.2	Sequence of activities	The sequence of activities in managed in a way that relationships among them are maintained while resources and equipment are used efficiently.	No												
		4.3	Constructability	4D planning helps in ensuring the soundness of a project and the use of alternative construction strategies if needed.	Yes	Intangible											
		4.4	Visualisation for the client	Visual represenation of the schedule combined with additional information visualised (4D CAD) helps the client understand the progress. This increases the possibility for proposals to be accepted by the client.	No												
5	4D Progress Monitoring																
		5.1	Project Monitoring	4D planning allows visualisation and tracking of the progress of the activities. In this way, problems can be detected and resolved on time. This contributes in efficient control of the project and facilitates the supervision of the project team.	Yes	Intangible									10% time saving		
6	5D Model for Cost Estimating																
		6.1	Cost Estimation	5D model contributes in accurate cost estimation before the initiation of the project in comparison to the traditional methods	No										80% reduction in time		
		6.2	Accuracy of Cost Estimation	5D model ensures higher accuracy in the cost estimation.	No										3% higher accuracy		
		6.3	Testing of Scenarios	Alternative scenarios regarding costs can be explored according to the requirements of the client and the contractor.	No												
7	Site Data Capturing																
		7.1	Paperless way of working	Site data capture enhances the visual representation of the actual conditions. This helps in going paperless and thus reducing the hidden costs of storing the paper documents on-site.	No												
		7.2	Efficiency of Data Collection and Handover	The degree to which digital Quality Control tools would make the data handover between the office and site more efficient.	No												
		7.3	Accuracy of the result	Site data capture ensures accurate depiction of the real situation on-site. Therefore, at the final stage, the project can be verified according to the initial plan.	No												
8	Added Value																
		8.1	BIM as a requirement from the client	If BIM implementation constitutes a requirement from the client then the contract may acquire an added value for the contractor because of this provision.	No												
		8.2	Prestige of the company	BIM implementation enhaces the name of the company within the international construction industry and adds value to its competitive image.	Yes	Intangible											
	Costs															2962080	
		Cr	Operational costs ($/day)	121.000,00													
		Cw	Cost of personnel ($)	379.415,62													
		Ch	Cost of hardware ($)	5.753,64													B/C ratio
		Cs	Cost of software ($)	13.456,35													8,063794293
		Ct	Total Costs ($)	398.625,00													
		B	Total Benefit ($)	3.214.430,00													

APPENDIX B

TABLE OF QUANTIFICATION OF LCA – UK

Sequence Number	Workflow	Code	Benefits	Definition	Project (LCA)	Tangible/Intagible	Quantifiable with; saving of time, reduction of waste, added value	Duration with BIM (hrs) (Tn)	Duration without BIM (hrs) (Tt)	Required Resources (number of people)	Saving of time (Δt*Required Resources)	Materials with BIM (Qn)	Materials without BIM (Qt)	Added Contract Value	Literature Reference	Cost Saving	Additional Information
1	3D Permanent Model																
		1.1	Requests for Information	Requests for Information are issued if conflicts among the elements are detected of if there are defficiencies. When these conflicts are solved on-time, time is saved during the construction phase.	Yes	Tangible	Saving of time	0	27,14	1	27,14				40% elimination of unbudgeted change	€ 1.248.440	
		1.2	Visualization of Risks and Opportunities	The degree to which the visualization of Permanent Works within a 3D model aids in visualizing either risks and/or opportunities.	Yes	Tangible										€ 465.695	
		1.3	Clash Detection & Design Changes	Clashes among the Architectural, Structural and MEP works can be deteted. Once they are detected, changes in design can be made and the 3D model is updated automatically. This leads to prevention of future mistakes.	Yes	Intangible									10% of the contract value		
		1.4	As-Built Drawings	During project execution the 3D model is constantly updated according to the changes. At the end of the project, the as-built model conditions are defined and as-built drawings can be extracted easily.	Yes	Intangible											
		1.5	Coordination of utilities	Especially in large and complex projects which involve numerous activities, the coordination of the interfaces is essential in order to avoid confusion on-site and time delays.	Yes	Intangible											
		1.6	Collaboration	Information sharing facilitates the communication and enhances the collaboration among the stakeholders.	Yes	Intangible									35%		
		1.7	Increased Documentation/Claims	Information is managed and used properly. In this way, the understanding of the client is increased and there is high chance of speeding-up the construction process.	Yes	Intangible											
2	3D Model for Quantity Take-off																
		2.1	Complexity of Structure (Shape)	The shape of the structure is of such complexity that it is not quantifiable without the use of a 3D model.	No												
		2.2	Efficiency of Processes (Time)	The 3D model helps in creating BOQ in a time-efficient way.	Yes	Intangible										€ 55.224	
		2.3	Accuracy of Estimate	The 3D Model provides higher accuracy of quantity estimates than traditional methods. Consequently, errors and over-ordering are avoided and waste of materials is reduced.	Yes	Intangible										€ 958.632	
		2.4	Variation Control	The degree to which 3D model adds value when controlling a project under uncertain conditions.	Yes	Intangible											
		2.5	Efficiency of Data Handover	The degree to which 3D model would make the data handover between the office and site more efficient.	Yes	Intangible											
3	3D Based Surveying																
		3.1	Complexity of Projects	The complexity of some projects makes the surveying hard and time-consuming.	No												
		3.2	Efficiency of Data Handover	If the 3D model is directly installed on the total station, the on-site coordination is achieved faster.	No												
4	4D Model for Planning																
		4.1	Interface coordination	Especially in large and complex projects which involve numerous activities, the coordination of the interfaces is essential in order to avoid confusion on-site and time delays.	Yes	Intangible											
		4.2	Sequence of activities	The sequence of activities in managed in a way that relationships among them are maintained while resources and equipment are used efficiently.	Yes	Intangible											
		4.3	Constructability	4D planning helps in ensuring the soundness of a project and the use of alternative construction strategies if needed.	Yes	Intangible											
		4.4	Visualisation for the client	Visual represenation of the schedule combined with additional information visualised (4D CAD) helps the client understand the progress. This increases the possibility for proposals to be accepted by the client.	Yes	Intangible											
5	4D Progress Monitoring																
		5.1	Project Monitoring	4D planning allows visualisation and tracking of the progress of the activities. In this way, problems can be detected and resolved on time. This contributes in efficient control of the project and facilitates the supervision of the project team.	Yes	Intangible									10% time saving		
6	5D Model for Cost Estimating																
		6.1	Cost Estimation	5D model contributes in accurate cost estimation before the initiation of the project in comparison to the traditional methods	Yes	Tangible									80% reduction in time		
		6.2	Accuracy of Cost Estimation	5D model ensures higher accuracy in the cost estimation.	Yes	Intangible									3% higher accuracy		
		6.3	Testing of Scenarios	Alternative scenarios regarding costs can be explored according to the requirements of the client and the contractor.	Yes	Intangible											
7	Site Data Capturing																
		7.1	Paperless way of working	Site data capture enhances the visual representation of the actual conditions. This helps in going paperless and thus reducing the hidden costs of storing the paper documents on-site.	Yes	Intangible											
		7.2	Efficiency of Data Collection and Handover	The degree to which digital Quality Control tools would make the data handover between the office and site more efficient.	Yes	Intangible											
		7.3	Accuracy of the result	Site data capture ensures accurate depiction of the real situation on-site. Therefore, at the final stage, the project can be verified according to the initial plan.	Yes	Intangible											
8	Added Value																
		8.1	BIM as a requirement from the client	If BIM implementation constitutes a requirement from the client then the contract may acquire an added value for the contractor because of this provision.	No												
		8.2	Prestige of the company	BIM implementation enhaces the name of the company within the international construction industry and adds value to its competitive image.	Yes	Intangible											
	Costs																
		Cr	Operational costs (£/day)	45.556,94													
		Cw	Cost of personnel (£)	580.133,74													
		Ch	Cost of hardware (£)	17.774,34													B/C ratio
		Cs	Cost of software (£)	97.097,14													
		Ct	Total Costs (£)	695.005,22													3,925137802
		B	Total Benefit (£)	2.727.991,26													

TABLE OF INPUTS FOR LCA

Group	Description	Unit of measure	Qty	Coef.	Weekly cost (£)	Unit cost (£)	Unit cost (€)	Total cost (€)
Hardware	BIM computers	Months	8	1	£ 130	£ 555	€ 655	€ 5.239
Hardware	Smart screen	ea	1	1	-	£ 10.323	€ 12.181	€ 12.181
Hardware	VR goggles	ea	1	1	-	£ 300	€ 354	€ 354
Software	BIM 360	Months	480	1	£ 10	£ 43	€ 51	€ 24.274
Software	Revit	Months	240	1	£ 20	£ 86	€ 101	€ 24.274
Software	Solibri	Months	48	1	£ 50	£ 214	€ 253	€ 12.137
Software	Revitzo	Months	48	1	£ 50	£ 214	€ 253	€ 12.137
Software	Navisworks	Months	240	1	£ 20	£ 86	€ 101	€ 24.274
Manpower	BIM Manager	LS (subcontract)	1	100%	£ 1	£ 116.069	€ 136.961	€ 136.961
Manpower	Project Information Manager	Months	24	50%	£ 1.370	£ 5.871	€ 6.928	€ 83.139
Manpower	Digital Apprentice	Months	24	100%	£ 500	£ 2.143	€ 2.529	€ 60.686
Manpower	Engineering Manager	Months	30	10%	£ 3.379	£ 14.481	€ 17.088	€ 51.264
Manpower	Doc. Controller	Months	30	10%	£ 1.052	£ 4.509	€ 5.320	€ 15.960
Manpower	4D Planner	Months	24	10%	£ 2.000	£ 8.571	€ 10.114	€ 24.274
Manpower	Engineers	Months	150	20%	£ 1.370	£ 5.871	€ 6.928	€ 207.849

APPENDIX C

TABLE OF QUANTIFICATION OF MOF – DUBAI, UAE

Sequence Number	Workflow	Code	Benefits	Definition	Project (MoF)	Tangible/Intangible	Quantifiable with; saving of time, reduction of waste, added value	Duration with BIM (hrs) (Tn)	Duration without BIM (hrs) (Tt)	Required Resources (number of people)	Saving of time (Δt*Required Resources)	Materials with BIM (Qn)	Materials without BIM (Qt)	Added Contract Value	Literature Reference	Cost Saving	Additional Information
1	3D Permanent Model																
		1.1	Requests for Information	Requests for Information are issued if conflicts among the elements are detected of if there are defficiencies.	Yes	Intangible											
		1.2	Visualization of Risks and Opportunities	The degree to which the visualization of Permanent Works within a 3D model aids in visualizing either risks and/or opportunities.	Yes	Intangible											
		1.3	Clash Detection & Design Changes	Clashes among the Architectural, Structural and MEP works can be deteted. Once they are detected, changes in design can be made and the 3D model is updated automatically. This leads to prevention of future mistakes.	Yes	Tangible	Saving of time	0	8190	5	40950					€ 109.865,85	
		1.4	As-Built Drawings	During project execution the 3D model is constantly updated according to the changes. At the end of the project, the as-built model conditions are defined and as-built drawings can be extracted easily.	Yes	Intangible											
		1.5	Coordination of utilities	Especially in large and complex projects which involve numerous activities, the coordination of the interfaces is essential in order to avoid confusion on-site and time delays.	Yes	Intangible											
		1.6	Collaboration	Information sharing facilitates the communication and enhances the collaboration among the stakeholders.	Yes	Intangible											
		1.7	Increased Documentation/Claims	Information is managed and used properly. In this way, the understanding of the client is increased and there is high chance of speeding-up the construction process.	Yes	Intangible											
2	3D Model for Quantity Take-off																
		2.1	Complexity of Structure (Shape)	The shape of the structure is of such complexity that it is not quantifiable without the use of a 3D model.	Yes	Tangible	Saving of time	5	300	5	295					€ 5.540,24	
		2.2	Efficiency of Processes (Time)	The 3D model helps in creating BOQ in a time-efficient way.	Yes	Tangible	Saving of time	65	1150	11	11935					€ 27.231,71	Using link model to field to set out MEP supports. Case study 7000 Bracket Points in basement (Based on Working 12 hours/day 7 days/week) 3 Teams of 3 men = 25 weeks RTS operator + 2 men = 11 days
		2.3	Accuracy of Estimate	The 3D Model provides higher accuracy of quantity estimates than traditional methods. Consequently, errors and over-ordering are avoided and waste of materials is reduced.	Yes	Intangible											
		2.4	Variation Control	The degree to which 3D model adds value when controlling a project under uncertain conditions.	Yes	Intangible											
		2.5	Efficiency of Data Handover	The degree to which 3D model would make the data handover between the office and site more efficient.	Yes	Intangible											
3	3D Based Surveying																
		3.1	Complexity of Projects	The complexity of some projects makes the surveying hard and time-consuming.	Yes	Intangible											
		3.2	Efficiency of Data Handover	If the 3D model is directly installed on the total station, the on-site coordination is achieved faster.	Yes	Intangible											
4	4D Model for Planning																
		4.1	Interface coordination	Especially in large and complex projects which involve numerous activities, the coordination of the interfaces is essential in order to avoid confusion on-site and time delays.	Yes	Intangible											
		4.2	Sequence of activities	The sequence of activities in managed in a way that relationships among them are maintained while resources and equipment are used efficiently.	No												
		4.3	Constructability	4D planning helps in ensuring the soundness of a project and the use of alternative construction strategies if needed.	Yes	Intangible											
		4.4	Visualisation for the client	Visual represenation of the schedule combined with additional information visualised (4D CAD) helps the client understand the progress. This increases the possibility for proposals to be accepted by the client.	Yes	Intangible											
5	4D Progress Monitoring																
		5.1	Project Monitoring	4D planning allows visualisation and tracking of the progress of the activities. In this way, problems can be detected and resolved on time. This contributes in efficient control of the project and facilitates the supervision of the project team.	Yes	Intangible									10% time saving		
6	5D Model for Cost Estimating																
		6.1	Cost Estimation	5D model contributes in accurate cost estimation before the initiation of the project in comparison to the traditional methods	Yes	Intangible											
		6.2	Accuracy of Cost Estimation	5D model ensures higher accuracy in the cost estimation.	Yes	Intangible											
		6.3	Testing of Scenarios	Alternative scenarios regarding costs can be explored according to the requirements of the client and the contractor.	Yes	Intangible											
7	Site Data Capturing																
		7.1	Paperless way of working	Site data capture enhances the visual representation of the actual conditions. This helps in going paperless and thus reducing the hidden costs of storing the paper documents on-site.	No												
		7.2	Efficiency of Data Collection and Handover	The degree to which digital Quality Control tools would make the data handover between the office and site more efficient.	Yes	Tangible	Saving of time	3	840	7	837					€ 15.719,27	
		7.3	Accuracy of the result	Site data capture ensures accurate depiction of the real situation on-site. Therefore, at the final stage, the project can be verified according to the initial plan.	Yes	Tangible	Saving of time	563	7313,25	3	6750,25					€ 18.563,19	
8	Added Value																
		8.1	BIM as a requirement from the client	If BIM implementation constitutes a requirement from the client then the contract may acquire an added value for the contractor because of this provision.	Yes	Intangible											
		8.2	Prestige of the company	BIM implementation enhaces the name of the company within the international construction industry and adds value to its competitive image.	Yes	Intangible											
	Costs																
		Cr	Operational costs (€/day)	30.000,00													
		Cw	Cost of personnel (€)	1.504.000,00													
		Ch	Cost of hardware (€)	26.158,00													B/C ratio
		Cs	Cost of software (€)	12.500,00													
		Ct	Total Costs (€)	1.542.658,00													1,114685342
		B	Total Benefit (€)	1.719.578,26													

APPENDIX D

TABLE OF COST OF SOFTWARE – IKEA, JAKARTA

Software	Price (per user per month)	Users	Duration (in months)	Total Cost
TP (Team Project)	€ 14,00	6	13	€ 1.092,00
CAD	€ 100,80	3	13	€ 3.931,20
Revit	€ 134,40	5	13	€ 8.736,00
Sharepoint	€ 450,00	1	13	€ 5.850,00
				€ 19.609,20

TABLE OF COST OF HARDWARE

Hardware	Price (per user)	Users	Total Cost
Computers	€ 1.200,00	5	€ 6.000,00

TABLE OF COST OF PERSONNEL

BAM International

Personnel	Resources	Duration (in months)	Manhours	Average cost (per manhour)
BIM Engineer	1	8	192	€ 19,11
Bim modeller	2	15	192	€ 19,11
Document Controller	1	13	192	€ 19,11
Drafter	3	33	192	€ 19,11
	Total	69	13248	€ 253.169,28

Subcontractors

Personnel	Resources	Items	Total Manhours	Average cost (per manhour)	Total Cost
BIM Modellers	1	Concrete elements GF to L2	8.742	€ 14,46	€ 126.409,32

Personnel	Resources	Items	Total Manhours	Average cost (per manhour)	Total Cost
BIM Modellers	1	Concrete elements B2 to B1	5.152	€ 19,11	€ 98.454,72

Summarised Cost of Personnel

Name	Total Manhours	Number of sheets	Price per manhour	Hours per sheet	Total Cost per Contractor
BAM International & Denki	13248,00	906	€ 19,11	14,62	€ 253.169,28
Archetype	8742,00	633	€ 14,46	13,81	€ 126.409,32
BAM Infra	5152,00	388	€ 19,11	13,28	€ 98.454,72
Total	27142,00	1927	-	-	€ 478.033,32

TABLE OF COST OF BIM IMPLEMENTATION

Item	Total Cost
Software	€ 19.609,20
Hardware	€ 6.000,00
Personnel	€ 478.033,32
SUM	€ 503.642,52

Name	Hours per sheet	Number of sheets	Total Manhours	Price per manhour
BAM International & Denki	25,00	906	22650,00	€ 19,11
Archetype	25,00	633	15825,00	€ 14,46
BAM Infra	25,00	388	9700,00	€ 19,11
Total	-	1927	48175,00	-

APPENDIX E

TABLE OF QUANTIFICATION OF IKEA PROJECT – JAKARTA

Sequence Number	Workflow	Code	Benefits	Definition	Project (IKEA project)	Tangible/Intagible	Quantifiable with; saving of time, reduction of waste, added value	Duration with BIM (hrs) (Tn)	Duration without BIM (hrs) (Tt)	Required Resources (number of people)	Saving of time (Δt*Required Resources)	Materials with BIM (Qn)	Materials without BIM (Qt)	Added Contract Value	Literature Reference	Cost Saving	Additional Information
1	3D Permanent Model																
		1.1	Requests for Information	Requests for Information are issued if conflicts among the elements are detected of if there are defficiencies.	Yes	Tangible	Saving of time	4.400,00	8.800,00	3 trade team of 2 people	4.400,00				40% elimination of unbudgeted change	88000,00	20 Euro / hour
		1.2	Visualization of Risks and Opportunities	The degree to which the visualization of Permanent Works within a 3D model aids in visualizing either risks and/or opportunities.	Yes	Tangible	Added value								Risk of 1 month delay	250000,00	Avoiding Risk of Delay due to Clash not detected between MEP and Structure, reworks for structural works
		1.3	Clash Detection & Design Changes	Clashes among the Architectural, Structural and MEP works can be deteted. Once they are detected, changes in design can be made and the 3D model is updated automatically. This leads to prevention of future mistakes.	Yes	Tangible	Saving of time, Added Value	2.000,00	4.000,00	2p for 8 months -> 2p for 4 months	2.000,00				10% of the contract value	40000,00	20 Euro / hour
		1.4	As-Built Drawings	During project execution the 3D model is constantly updated according to the changes. At the end of the project, the as-built model conditions are defined and as-built drawings can be extracted easily.	Yes	Tangible	Saving of time	500,00	2.000,00	4p for 2 months -> 2p for 1 months (finetuning)	1.500,00					30000,00	20 Euro / hour
		1.5	Coordination of utilities	Especially in large and complex projects which involve numerous activities, the coordination of the interfaces is essential in order to avoid confusion on-site and time delays.	Yes	Intangible											
		1.6	Collaboration	Information sharing facilitates the communication and enhances the collaboration among the stakeholders.	Yes	Tangible	Added value								BIM contributed to the claim	37500,00	Additional VO identified during Collaboration process in BIM
		1.7	Increased Documentation/Claims	Information is managed and used properly. In this way, the understanding of the client is increased and there is high chance of speeding-up the construction process.	Yes	Tangible	Added value								BIM contributed to 20% of the claim evidences and as major factor in the identification of design change	200000,00	EOT claim of 1 million Euro (projected success rate)
2	3D Model for Quantity Take-off																
		2.1	Complexity of Structure (Shape)	The shape of the structure is of such complexity that it is not quantifiable without the use of a 3D model.	No												
		2.2	Efficiency of Processes (Time)	The 3D model helps in creating BOQ in a time-efficient way.	Yes	Intangible											
		2.3	Accuracy of Estimate	The 3D Model provides higher accuracy of quantity estimates than traditional methods. Consequently, errors and over-ordering are avoided and waste of materials is reduced.	Yes	Intangible											
		2.4	Variation Control	The degree to which 3D model adds value when controlling a project under uncertain conditions.	Yes	Intangible											
		2.5	Efficiency of Data Handover	The degree to which 3D model would make the data handover between the office and site more efficient.	Yes	Intangible											
3	3D Based Surveying																
		3.1	Complexity of Projects	The complexity of some projects makes the surveying hard and time-consuming.	No												
		3.2	Efficiency of Data Handover	If the 3D model is directly installed on the total station, the on-site coordination is achieved faster.	No											-	
4	4D Model for Planning																
		4.1	Interface coordination	Especially in large and complex projects which involve numerous activities, the coordination of the interfaces is essential in order to avoid confusion on-site and time delays.	No												
		4.2	Sequence of activities	The sequence of activities in managed in a way that relationships among them are maintained while resources and equipment are used efficiently.	No												
		4.3	Constructability	4D planning helps in ensuring the soundness of a project and the use of alternative construction strategies if needed.	No												
		4.4	Visualisation for the client	Visual represenation of the schedule combined with additional information visualised (4D CAD) helps the client understand the progress. This increases the possibility for proposals to be accepted by the client.	No												
5	4D Progress Monitoring																
		5.1	Project Monitoring	4D planning allows visualisation and tracking of the progress of the activities. In this way, problems can be detected and resolved on time. This contributes in efficient control of the project and facilitates the supervision of the project team.	No												
6	5D Model for Cost Estimating																
		6.1	Cost Estimation	5D model contributes in accurate cost estimation before the initiation of the project in comparison to the traditional methods	No												
		6.2	Accuracy of Cost Estimation	5D model ensures higher accuracy in the cost estimation.	No												
		6.3	Testing of Scenarios	Alternative scenarios regarding costs can be explored according to the requirements of the client and the contractor.	No												
7	Site Data Capturing																
		7.1	Paperless way of working	Site data capture enhances the visual representation of the actual conditions. This helps in going paperless and thus reducing the hidden costs of storing the paper documents on-site.	No												
		7.2	Efficiency of Data Collection and Handover	The degree to which digital Quality Control tools would make the data handover between the office and site more efficient.	No												
		7.3	Accuracy of the result	Site data capture ensures accurate depiction of the real situation on-site. Therefore, at the final stage, the project can be verified according to the initial plan.	No												
8	Added Value																
		8.1	BIM as a requirement from the client	If BIM implementation constitutes a requirement from the client then the contract may acquire an added value for the contractor because of this provision.	No												
		8.2	Prestige of the company	BIM implementation enhaces the name of the company within the international construction industry and adds value to its competitive image.	Yes	Intangible											
	Costs																
		Cr	Operational costs (€/day)	-													
		Cw	Cost of personnel (€)	478.033,32													
		Ch	Cost of hardware (€)	6.000,00													B/C ratio
		Cs	Cost of software (€)	19.609,20													
		Ct	Total Costs (€)	503.642,52													2,014999607
		B	Total Benefit (€)	1.014.839,48													

APPENDIX F

TABLE OF QUANTIFICATION OF BAS – UK ANTARCTIC

Sequence Number	Workflow	Code	Benefits	Definition	Project (BAS)	Tangible/Intangible	Quantifiable with; saving of time, reduction of waste, added value	Duration with BIM (hrs) (Tn)	Duration without BIM (hrs) (Tt)	Required Resources (number of people)	Saving of time (Δt*Required Resources)	Materials with BIM (Qn)	Materials without BIM (Qt)	Added Contract Value	Literature Reference	Cost Saving	Additional Information
1	3D Permanent Model																
	Issue via PW	1.1	Requests for Information	Requests for Information are issued if conflicts among the elements are detected of if there are defficiencies.	Yes	Intangible											
	Earthworks Modelling	1.2	Visualization of Risks and Opportunities	The degree to which the visualization of Permanent Works within a 3D model aids in visualizing either risks and/or opportunities.	Yes	Tangible	Reduction of waste (Minimum Rehandling of material)					0	7200		£15/m3 to move blasted rock. Estiimated 1/3rd	£108.000,00	
	Reduced waste, Accurate Construction Drawings, Faster Conflict resolution	1.3	Clash Detection & Design Changes	Clashes among the Architectural, Structural and MEP works can be deteted. Once they are detected, changes in design can be made and the 3D model is updated automatically. This leads to prevention of future mistakes.	Yes	Tangible	Saving of time	200	800	6	3600				£25ph for BIM Engineer	£90.000,00	Not all benefits are tangeable, Reduced waste on site, reduced rework, Faster Resolution, Better communication
	Easier Handover	1.4	As-Built Drawings	During project execution the 3D model is constantly updated according to the changes. At the end of the project, the as-built model conditions are defined and as-built drawings can be extracted easily.	Yes	Intangible											
	Model Linking, Clash Detection	1.5	Coordination of utilities	Especially in large and complex projects which involve numerous activities, the coordination of the interfaces is essential in order to avoid confusion on-site and time delays.	Yes	Intangible											
	VR, Model Sharing	1.6	Collaboration	Information sharing facilitates the communication and enhances the collaboration among the stakeholders.	Yes	Intangible											
	Clash Detection, Model raising more TQs, Easier Visualisation of finished potential issues.	1.7	Increased Documentation/Claims	Information is managed and used properly. In this way, the understanding of the client is increased and there is high chance of speeding-up the construction process.	Yes	Intangible											
2	3D Model for Quantity Take-off																
		2.1	Complexity of Structure (Shape)	The shape of the structure is of such complexity that it is not quantifiable without the use of a 3D model.	No												
		2.2	Efficiency of Processes (Time)	The 3D model helps in creating BOQ in a time-efficient way.	No												
	Take Offs used, though manual checks still requried.	2.3	Accuracy of Estimate	The 3D Model provides higher accuracy of quantity estimates than traditional methods. Consequently, errors and over-ordering are avoided and waste of materials is reduced.	Yes	Tangible	Saving of time	50	1000	1	950				Cost OS	£23.750,00	Use of CostOS through the Estimation phase and into the project to monitor changes to the design. Difficult to qunatify fully, however estimate has been made.
		2.4	Variation Control	The degree to which 3D model adds value when controlling a project under uncertain conditions.	No												
		2.5	Efficiency of Data Handover	The degree to which 3D model would make the data handover between the office and site more efficient.	No												
3	3D Based Surveying																
		3.1	Complexity of Projects	The complexity of some projects makes the surveying hard and time-consuming.	No												3D Surveying not used on the Project.
		3.2	Efficiency of Data Handover	If the 3D model is directly installed on the total station, the on-site coordination is achieved faster.	No												
4	4D Model for Planning																
	Phasing/Planning	4.1	Interface coordination	Especially in large and complex projects which involve numerous activities, the coordination of the interfaces is essential in order to avoid confusion on-site and time delays.	Yes	Tangible	Saving of time	400	1200	4	3200			Reduction in project timeline - 2 weeks at site running costs of ~£50,000 p/wk. Therefore, additional saving of £100,000	Synchro Pro / Autodesk Navisworks	£80.000,00	
	Phasing/Planning	4.2	Sequence of activities	The sequence of activities in managed in a way that relationships among them are maintained while resources and equipment are used efficiently.	Yes	Tangible	Saving of time	200	600	1	400				Synchro Pro / Autodesk Navisworks	£10.000,00	More defined Construction Programme, Higher accuracy in Planning, Less Coservative Float assumptions, More clarity in information exchange.
	Meetings to view 3D meeting and discuss constructability	4.3	Constructability	4D planning helps in ensuring the soundness of a project and the use of alternative construction strategies if needed.	Yes	Tangible	Saving of time	200	600	1	400				Synchro Pro / Autodesk Navisworks	£10.000,00	
		4.4	Visualisation for the client	Visual represenation of the schedule combined with additional information visualised (4D CAD) helps the client understand the progress. This increases the possibility for proposals to be accepted by the client.	Yes	Intangible								Reduction in time required to explain programme to the client and site personnel will lead to reduced costs. Site personnel understanding the construciton sequence will result in improved efficiency on site			
5	4D Progress Monitoring																
	Ongoing updates based on progress	5.1	Project Monitoring	4D planning allows visualisation and tracking of the progress of the activities. In this way, problems can be detected and resolved on time. This contributes in efficient control of the project and facilitates the supervision of the project team.	Yes	Intangible											Covid-19 Ability to produce different programmes based on constraints.
6	5D Model for Cost Estimating																
		6.1	Cost Estimation	5D model contributes in accurate cost estimation before the initiation of the project in comparison to the traditional methods	No												
		6.2	Accuracy of Cost Estimation	5D model ensures higher accuracy in the cost estimation.	No												
		6.3	Testing of Scenarios	Alternative scenarios regarding costs can be explored according to the requirements of the client and the contractor.	No												
7	Site Data Capturing																
	Workmobile to capture ITCs etc	7.1	Paperless way of working	Site data capture enhances the visual representation of the actual conditions. This helps in going paperless and thus reducing the hidden costs of storing the paper documents on-site.	Yes	Tangible	Saving of time	30	450	2	840				£50/ph per Engineer	£42.000,00	Utilising tech to carry out Tests and records on site, removed paper work and rentering data into computer at end of shift. Allowed Engineers to be on site for longer and continue with the works.
	Not yet commenced	7.2	Efficiency of Data Collection and Handover	The degree to which digital Quality Control tools would make the data handover between the office and site more efficient.	No												
	Workmobile and reporting back to UK	7.3	Accuracy of the result	Site data capture ensures accurate depiction of the real situation on-site. Therefore, at the final stage, the project can be verified according to the initial plan.	No												
8	Added Value																
		8.1	BIM as a requirement from the client	If BIM implementation constitutes a requirement from the client then the contract may acquire an added value for the contractor because of this provision.	Yes	Intangible											
		8.2	Prestige of the company	BIM implementation enhaces the name of the company within the international construction industry and adds value to its competitive image.	Yes	Intangible											
	Costs																
		Cr	Operational costs (£/day)	8.333,33													
		Cw	Cost of personnel (£)	150.000,00													
		Ch	Cost of hardware (£)	3.150,00													B/C ratio
	Revit, Autodesk CAD, Autodesk Live, Naviswork Manage (All 2019 versions), Solibri	Cs	Cost of software (£)	4.500,00													2,94164288
		Ct	Total Costs (£)	157.650,00													
		B	Total Benefit (£)	463.750,00													

APPENDIX G

RESULTS OF SENSITIVITY ANALYSIS FOR 1% CHANGE

APM Terminal - Moin, Costa Rica					
Cost	B/C	Lower Boundary	Upper Boundary	Percentage Positive	Percentage Negative
Personnel	398625,61	394831,4538	402419,7662	0,95%	0,94%
Hardware	398625,61	398568,0736	398683,1464	0,01%	0,01%
Software	398625,61	398491,0465	398760,1735	0,03%	0,03%

LCA - London, UK					
Cost	Total Cost	Lower Boundary	Upper Boundary	Percentage Negative	Percentage Positive
Personnel	695005,22	689203,8823	700806,557	0,83%	0,83%
Hardware	695005,22	694827,4763	695182,9631	0,03%	0,03%
Software	695005,22	694034,2482	695976,1911	0,14%	0,14%

Museum Of The Future - Dubai, UAE					
Cost	Total Cost	Lower Boundary	Upper Boundary	Percentage Negative	Percentage Positive
Personnel	1542658	1527618	1557698	0,97%	0,97%
Hardware	1542658	1542396,42	1542919,58	0,02%	0,02%
Software	1542658	1542533	1542783	0,01%	0,01%

IKEA Project - Indonesia, Jakarta					
Cost	Total Costs	Lower Boundary	Upper Boundary	Percentage Positive	Percentage Negative
Personnel	503642,52	498862,1868	508422,8532	0,95%	0,94%
Hardware	503642,52	503642,52	503642,52	0,00%	0,00%
Software	503642,52	503446,428	503838,612	0,04%	0,04%

British Antarctic Survey - UK Antarctica					
Cost	Total Costs	Lower Boundary	Upper Boundary	Positive Change	Negative Change
Personnel	157650	156150	159150	0,95%	0,94%
Hardware	157650	157618,5	157681,5	0,02%	0,02%
Software	157650	157605	157695	0,03%	0,03%

APPENDIX F

Interview Protocol for Validation of the Model

1. Do you have any comments/suggestions/points of improvement on the proposed Framework?

2. How would you assess the validity and soundness of the Framework?

3. Do you think this Framework is flexible to apply in other projects? If yes, would you apply it? If no, which changes would you make?

4. In which way could this Framework be adopted by a company? Would it require special organisational or managerial adjustments?

5. Which impact could this Framework have on the BIM strategy of a company?

APPENDIX H

TABLE OF QUANTIFICATION OF SIR BANI YAS – UAE

Sequence Number	Workflow	Code	Category	Definition of Benefits	Project (Sir Bani Yas)	Tangible/Intangible	Quantifiable with; saving of time, reduction of waste, added value	Duration with BIM (hrs) (Tn)	Duration without BIM (hrs) (Tt)	Required Resources (number of people)	Saving of time (Δt*Required Resources)	Saving of time (Δt*Required Equipment)	Materials with BIM (Qn)	Materials without BIM (Qt)	Added Contract Value	Literature Reference	Cost Saving	Additional Information
1	3D Permanent Model																	
		1.1	Requests for Information	Requests for Information are issued if conflicts among the elements are detected of if there are defficiencies. When these conflicts are solved on-time, time is saved during the construction phase.	No											40% elimination of unbudgeted change		
		1.2	Visualization of Risks and Opportunities	The degree to which the visualization of Permanent Works within a 3D model aids in visualizing either risks and/or opportunities.	No	Intangible												
		1.3	Clash Detection & Design Changes	Clashes among the Permanent, Temporary works and Reinforcement.	Yes	Tangible	Saving of time	9	70	1 Modeller	61					10% of the contract value	€ 3.068,30	
		1.4	As-Built Drawings	During project execution the 3D model is constantly updated according to the changes. At the end of the project, the as-built model conditions are defined and as-built drawings can be extracted easily.	No (yet)													
		1.5	Coordination of disciplines	Especially in large and complex projects which involve numerous activities, the coordination of the interfaces is essential in order to avoid confusion on-site and time delays.	No													
		1.6	Collaboration	Information sharing facilitates the communication and enhances the collaboration among the stakeholders.	No	Intangible										35%		
		1.7	Increased Documentation/Claims	Information is managed and used properly. In this way, the understanding of the client is increased and there is high chance of speeding-up the construction process.	No													
2	3D Model for Quantity Take-off																	
		2.1	Complexity of Structure (Shape)	The shape of the structure is of such complexity that it is not quantifiable without the use of a 3D model.	Yes	Intangible												
		2.2	Efficiency of Processes (Time)	The 3D model helps in creating BOQ in a time-efficient way.	Yes	Tangible	Saving of time	9	90	1 Modeller	81						€ 4.074,30	
		2.3	Accuracy of Estimate	The 3D Model provides higher accuracy of quantity estimates than traditional methods. Consequently, errors and over-ordering are avoided and waste of materials is reduced.	Yes	Tangible	Saving of time	4,5	45	1 Estimator	40,5						€ 2.754,00	
		2.4	Variation Control	The degree to which 3D model adds value when controlling a project under uncertain conditions.	No (yet)	Intangible												
		2.5	Efficiency of Data Handover	The degree to which 3D model would make the data handover between the office and site more efficient.	Yes	Intangible												
3	3D Based Surveying																	
		3.1	Complexity of Projects	The complexity of some projects makes the surveying hard and time-consuming.	No (yet)													
		3.2	Efficiency of Data Handover	If the 3D model is directly installed on the total station, the on-site coordination is achieved faster.	No (yet)													
4	4D Model for Planning																	
		4.1	Interface coordination	Especially in large and complex projects which involve numerous activities, the coordination of the interfaces is essential in order to avoid confusion on-site and time delays.	Yes	Tangible	Saving of time	20	50	1 Planner	30						€ 630,00	
		4.2	Sequence of activities	The sequence of activities in managed in a way that relationships among them are maintained while resources and equipment are used efficiently.	Yes	Tangible	Saving of time	20	50	1 Planner	30						€ 630,00	
		4.3	Constructability	4D planning helps in ensuring the soundness of a project and the use of alternative construction strategies if needed.	Yes	Tangible	Saving of time	30	85	1 Planner + 1 Modeler	110						€ 7.837,50	
		4.4	Visualisation for the client	Visual represenation of the schedule combined with additional information visualised (4D CAD) helps the client understand the progress. This increases the possibility for proposals to be accepted by the client.	Yes	Tangible	Saving of time	0.5 Hour/Week*50 Weeks	3 Hour/Week*50 Weeks	1 Planner	125						€ 2.625,00	
5	4D Progress Monitoring																	
		5.1	Project Monitoring	4D planning allows visualisation and tracking of the progress of the activities. In this way, problems can be detected and resolved on time. This contributes in efficient control of the project and facilitates the supervision of the project team.	Yes	Tangible	Saving of time	0.5 Hour/Week*50 Weeks	3 Hour/Week*50 Weeks	1 Planner	125					10% time saving	€ 2.625,00	
6	5D Model for Cost Estimating																	
		6.1	Cost Estimation	5D model contributes in accurate cost estimation before the initiation of the project in comparison to the traditional methods	No											80% reduction in time		
		6.2	Accuracy of Cost Estimation	5D model ensures higher accuracy in the cost estimation.	No											3% higher accuracy		
		6.3	Testing of Scenarios	Alternative scenarios regarding costs can be explored according to the requirements of the client and the contractor.	No													
7	Site Data Capturing																	
		7.1	Paperless way of working	Site data capture enhances the visual representation of the actual conditions. This helps in going paperless and thus reducing the hidden costs of storing the paper documents on-site.	No	(not yet applicable)												
		7.2	Efficiency of Data Collection and Handover	The degree to which digital Quality Control tools would make the data handover between the office and site more efficient.	No	(not yet applicable)												
		7.3	Accuracy of the result	Site data capture ensures accurate depiction of the real situation on-site. Therefore, at the final stage, the project can be verified according to the initial plan.	No	(not yet applicable)												
8	Added Value																	
		8.1	BIM as a requirement from the client	If BIM implementation constitutes a requirement from the client then the contract may acquire an added value for the contractor because of this provision.	No													
		8.2	Prestige of the company	BIM implementation enhaces the name of the company within the international construction industry and adds value to its competitive image.	Yes	Intangible												
	Costs																	
		Cr	Operational costs (€/day)															
		Cw	Cost of personnel (€)	11055,84														
		Ch	Cost of hardware (€)	2763,96														B/C ratio
		Cs	Cost of software (€)	4836,93														
		Ct	Total Costs (€)	18656,73														1,299482814
		B	Total Benefit (€)	24244,1														