# Digitalizing the construction site management

*Assessing and boosting the use of digital mobile tools for capturing data on construction on-site activities*

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"Humans are like an ever flowing river of fresh water.
We stagnate if we stop progressing."

**— Arshad Wahedna**

"Efficiency is doing better what is already being done"

**— Peter F. Drucker**

"The biggest part of the digital transformation is changing the way we think"

**— Simeon Preston**

# Preface

Dear Reader,

Before you, lies the graduation thesis titled “Digitalizing the construction site management”, in partial fulfilment of the Master of Science degree in Construction Management & Engineering at the University of Twente. This document is the result of 7 months of research, data gathering and report writing.

The research topic was easily chosen due to my high interest in digital construction and its’ processes, that have altered the scenery of the construction industry during the last decade. The research was performed on behalf of the ‘Royal BAM Group nv’. The aim of this thesis was to prove the benefits of using digital mobile tools on site and create a framework that can boost this implementation. The research proved to be time-consuming and demanded consistent work. However, the process fed me with a tremendous amount of knowledge in innovative techniques and insight on the digital construction notion.

To accomplish the successful completion of my graduation project, the assistance of several people was required. At first, I would like to thank my supervisors of the university, Hans Voordijk and Sander Siebelink, for their supervision and guidance to complete my dissertation. Moreover, I would like to express my gratitude to the company and BAM employees for their support. Particularly, I would like to thank David Milnes, Mark Taylor, Ivor Barbrook and the director of digital construction, Menno de Jonge. Finally, I would like to acknowledge the assistance of the interviewees and their warm welcome in the different projects I have visited.

Pavlos Stefanakis

Enschede, January 2019

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# Executive Summary


## *Intro*

The construction industry is the biggest industry in the world, with specific and unique characteristics, which makes it stand out from the other industries. Construction projects are becoming more complex and difficult to manage, due to the interdependencies of numerous multidisciplinary stakeholders. The site management process is still dominated by paper causing severe costs, errors and waste for the construction companies, and significant time on construction sites is devoted to performing non-value-activities, increasing the waste and rates of inefficiency. Therefore, the increase of efficiency, effectiveness, productivity and project quality, as well as decreasing project cost and delivery time are the most important topics that the construction industry attempts to accomplish today. The digital construction transformation has begun to constitute a key approach to achieve these aspects and meet the requirements of a contemporary construction project.

## *Objective*

The main objective of the study is to provide a sound methodology for BAM to effectively acknowledge the benefits and implementation barriers of the on-site digital technology as well as developing an implementation framework to boost the adoption of this technology in the company's future projects". In this study, the use of digital technology during the construction stage will be defined as the digital construction tools that are used to automate the site activities, by automatically record and share field data. Digital construction tools are defined all the BIM related tools, the mobile devices such as smartphones and tablet computers as well as the cloud-based applications that are used to digitally share the information extracted from the field among the project team members.

## *Methodology*

A case study approach was selected to assess the implementation of mobile digital construction tools on site. More specifically, the research took place in multiple projects of the Royal BAM Group, with duration one month (November 2018). The case-study within the Royal BAM Group, took place in the United Kingdom and involved personal interviews with construction practitioners, field observations and documentations.

## *Results*

The results of the research showed that the use of digital mobile tools provides important benefits to the users, project and the company. The most important benefit is the increase of efficiency of the users. The use of mobile tools can save significant amount of time, allowing people to think more about their role and how they can add value to the business. The next stage of the results identified the most crucial barriers that are hindering the adoption or successful implementation. The different reasons and problems were narrowed down to eight main barriers, that were presented within the study. After the identification of the barriers, the study provided effective recommendation of supportive actions to boost the adoption of these tools. The solutions were

divided into 3 main categories: the type of initiative (people, process, technology), the stage that should be put into effect (preliminary, pre-construction, construction, post-construction) and the level of importance (high, medium, low). The type derived from the data analysis of the interviews, whereas the other categories were originally developed within the research methodology. After the categorizations, the several proposed solutions were visualized through the development of a RoadMap. The RoadMap included all three of these dimensions (type, stage, importance) and aimed to provide an effective and sequenced representation of those actions, for an easier and more accurate implementation by the company, to boost the adoption of the digital mobile management tools. After the presentation and explanation of the RoadMap, the output (RoadMap) was validated from the deployment digital construction expert of Royal BAM, responsible for the communication with the software developers as well as leading the BAM digital strategy for site data capture. Both the case-study and the deployment expert, regarded the solution 'promoting a common approach' as the most impactful action to boost the adoption of the digital mobile site tools. To this extent, a practical recommendation, named as 'standardization model' in the research, was additionally provided in order to successfully reach a common approach for the site management.

### *Conclusion*

The objective of this research was to provide construction companies an overview about the benefits, the implementation barriers as well as providing a solid and detailed approach to overcome those barriers in order to get the maximum of the use of digital mobile site management tools. In light of the information gathered by the literature review and the case-study, it can be concluded that digital mobile site management applications should be preferred over the traditional paper-methods. A well-implemented digital process for capturing site data can provide important benefits and be a solution to the main problem of construction industry, the low productivity. Moreover, the dissertation managed to familiarize the company with the most important blockers to this adoption as well as showing a successful path to boost the use of the digital mobile tools in the company's projects through the use of the RoadMap.

**Keywords:** Digital Construction, Site Management, Mobile Devices, Cloud Software, Digital mobile site management tools

# 1. Introduction

The first chapter of this research will provide information about the digital construction and a short description of the Royal BAM company and its' objectives. Subsequently, the problem description will be elaborated, along with the motivation for performing the research. The chapter will be concluded with some remarks on the feasibility and the limitations of the study.

## 1.1 Introduction

The construction industry is the biggest industry in the world, with specific and unique characteristics, which makes it stand out from the other industries. Construction projects are becoming more complex and difficult to manage, due to the interdependencies of numerous multidisciplinary stakeholders (Becerik-Gerber, 2010). These projects are characterized as information intensive, making the smooth exchange of information an indispensable feature. Therefore, the successful completion of building projects requires accurate, continuous and on-time sharing of information among the project members (Mansson, 2016). Moreover, the construction industry has become a synonym of "inefficiency" which then leads to low productivity and profit margin levels. Significant time on construction sites is devoted to performing non-value-activities, increasing the waste and rates of efficiency. This need urges the industry to move away from previous traditional communication methods, towards contemporary digital methods. Cloud computing and mobile devices have recently made a dynamic introduction to construction sites, as an alternative way to capture site data. The most efficient way for construction personnel to manage information on sites is to retrieve or capture information at the point where they are and at the time when they need it (Chen and Kamara, 2008). This has been difficult to achieve with traditional information management methods, which normally involves paper-based documents. Bowden, et al. (2004) indicates that the main type of information that onsite construction personnel receive and transmit is paper-based. This poses a major constraint for communication on site. However, the rapid development of mobile and wireless communication technologies offers new possibilities for portable information systems and communication tools to construction personnel (Lofgren and Rebolj, 2007). The use of mobile devices, like tablets, has entered the construction sites in large parts of the world. However, implementation of tablets requires resources and reorganizing. This new era of information management tools (software-hardware) is setting the basis for some key concepts of the industry to be achieved. These concepts are the LEAN construction, automated data collection technology (ADCT) and lastly BIM (Building Information Modelling). BIM is expected to lead the construction industry to a whole new era, with the focus on the effective communication and exchange of information, establishing itself as a basic methodology for construction practitioners (Mansson, 2016). Building Information Modeling (BIM) as a virtual process has become a key approach in the construction industry in order to increases project efficiency and effectiveness through an improved collaboration (Dossick & Neff 2011) among project members. For example, starting from 2014, UK government has declared that all the members of the supply chain have to communicate and work through the use of BIM (Bryde,2012).

## 1.2 Problem statement

The 'digital transformation' has been introduced on the construction industry for a considerable time, however the industry has yet to adopt it and exploit its uses to the fullest (Becerik & Rice, 2010). The adoption of digital construction, as all IT investments for the building industry, become even more limited, due to fact that every project is unique and it has unique characteristics. However, it can also be attributed to the fact that the current digital technologies and tools are mostly developed for the offices. The technologies need to be built also for the field, where the main cost is attributed and the work is done. According to Construction Industry Institute (CII) the 75% of the total project costs, are spent on the field activities, whereas the 90% of the digital-technology is being developed for the office in the design and pre-construction phase (McGraw Hill, 2012). The majority of the scientific research has also focused in enhancing and discovering new technologies for the design-work in the office environment. There are only a few attempts to discover and test digital-based tools to enhance the on-site activities. To this extent, site management tasks are still dominated by papers, in the form of paper drawings and or paper notes for capturing information, causing severe costs, errors and delays during the execution phase (Davies and Harty, 2013). With over 25% of the money wasted during the field activities (McGraw Hill,2012), there is a massive need to successfully utilize digital tools on the field and increase, among others, the "low field productivity" which sadly has become a synonym of the construction industry. The following figure depicts the amount of time wasted in non-value added activities of the construction projects compared to the manufacturing industry.

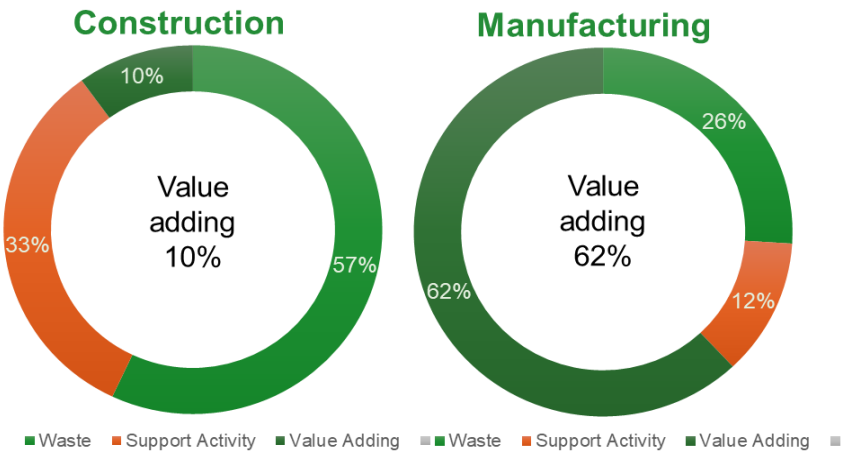



*Figure 1-Time allocation construction vs manufacturing*

Based on the aforementioned, the following problem definition can be stated:

***"The site management process is still dominated by paper causing severe costs, errors and waste for the construction companies".***

## 1.3 The company – Royal BAM Group

***About BAM***

Royal BAM Group is a successful European construction group, established in the Netherlands that unites operating companies in two business lines, Construction and property and Civil engineering. BAM is also active in the sector public private partnerships (PPP). With approximately 21,000 employees BAM delivers thousands of projects each year globally (Royal BAM group, 2018). The company was founded by Adam van der Wal as a joiner's shop in 1869. It was renamed Bataafsche Aanneming Maatschappij van Bouw- en Betonwerken ('BAM') in 1927 and expanded through acquisition buying Interbuild in 1998, NBM-Amstelland in 2000 and Hollandsche Beton Groep (later HBG) in 2002. BAM Group is consisted from 9 separate operating companies, that are located in United Kingdom, the Netherlands, Germany and Belgium, as shown in figure 1.

***Strategy***

Royal BAM is dedicated to maintaining a high level of expertise in project management and construction, inclusive of safety, quality and care for the environment. Their strategy emphasizes the importance of advanced construction techniques, a highly qualified management and staff, and a flexible organization enabling close co-operation with both associated and local experts. All supported by a sound financial base. In today's competitive market BAM's goal is to exceed the client's expectations, deliver on time and on budget and at the same time act sustainably and contribute positively to the communities. BAM's philosophy is to offer real value to the clients and work with them to provide the optimum solution (Royal BAM Group,2018).

***Digital Construction at BAM***

BAM is trying to stimulate digital ways of working. Using technological innovations such as BIM, robotics, 3D printing, virtual and augmented reality and modular/offsite construction, to enable to build digitally before building on site. The company's approach to digital is shaped from the outset by clients' requirements. They work within a common data environment to ensure the acquisition of the right data, at the right time for use across assets lifecycle. This ensures that assets are fit for purpose from day one and deliver the desired environmental, social and financial outcomes. BAM has adopted a market leading 'whole life BIM' approach, which spans the entire asset lifecycle (design, construction and operations) (Royal BAM Group,2018).

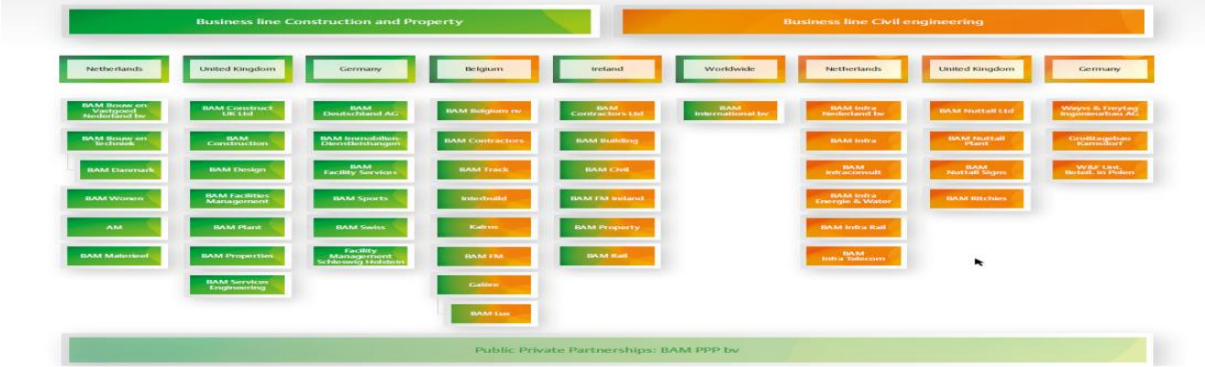



*Figure 2: Organization Royal BAM Group nv*

## 1.4 Motivation

In order to appoint a motive for this research, the strategic goal of the BAM and the problem statement, elaborated in the previous sub-chapter, should be taken into account. As has been discussed before in this proposal, BAM is currently focusing on becoming the leader in “digital construction”. To this extent, BAM has started an extensive collaboration program, including all international operating companies that are in collaboration with, aiming to boost the implementation of digitization in all their projects. The company is now seeking for a solid proof for digitizing the construction site management and also to get an indication of possible implementation barriers and drivers. Combined with the need of the construction industry to enhance the current site management process, this research will start by establishing the benefits of the mobile digital management tools. Furthermore, it will lead to a series of practical recommendations and insights for the Royal BAM Group, and for the industry as well, to increase the adoption of these tools.

## 1.5 Clarification of the study's purpose, approach and terminology

Prior to the development of the research questions and research methodology, it is important at this stage the clarification of the key terms, to avoid potential cohesion of the reader. Cheng and Singh (2017) have provided the different digital technology applications in the construction industry. The author is providing a visual representation of these applications in the following figure:

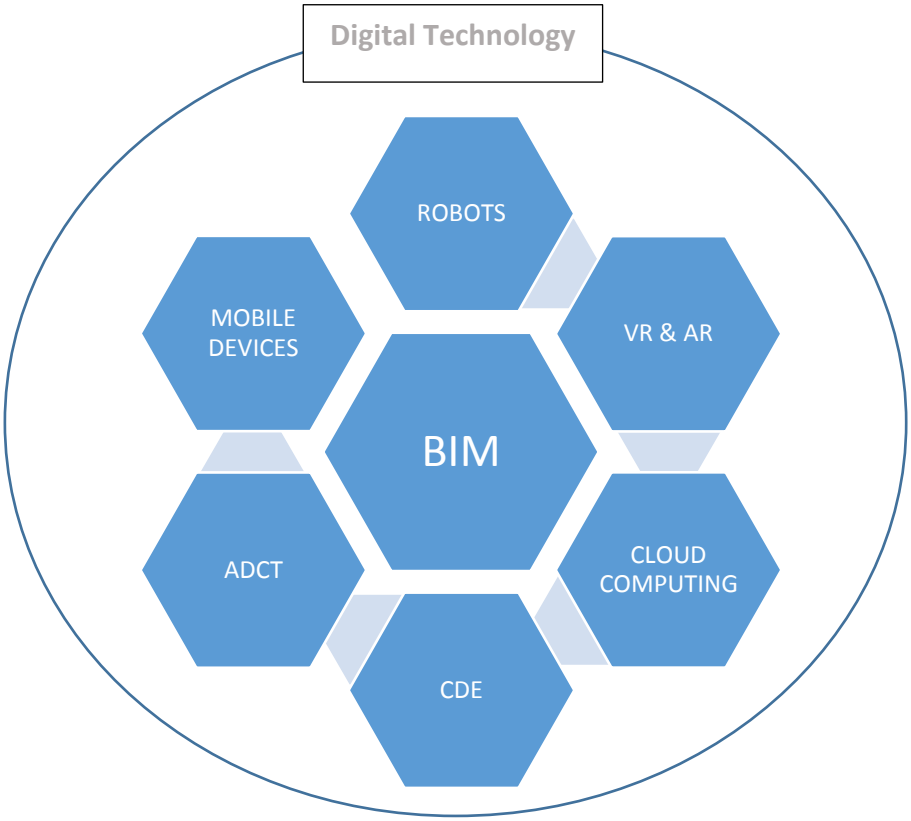



*Figure 3-Different digital construction applications*

As it can be seen from the figure above, BIM is an integral part of digital technology but it cannot replace the whole entity of it. Many of the scientific studies, are investigating strictly the use of BIM mobile tools for the enhancement of the site management processes. However, there is limited proof if the BIM mobile applications are providing the biggest benefits comparing to other mobile digital applications. The present study is adopting a more holistic view of the digitization, without being restricted on the BIM processes. Rather than investigating solely the BIM mobile tools, the use of all digital mobile tools is preferred. The reason behind this logic is based on 2 aspects. The first is that the author wants to explore the most effective digital processes in the construction sites of BAM, without taking for granted that these processes are BIM-based. Another reason for that is that the author cannot be aware if the projects are utilizing BIM mobile tools or other digital mobile applications to execute their tasks. However, the existing literature suggests that use of site-BIM is the most effective approach for the site management processes.

This study will explore the benefits and barriers of the digital tools on-site and provide an overview of the best digital practices implemented in the projects. The clarification of the difference between digital mobile tools and BIM mobile tools, is important for the easier and appropriate understanding of the reader.

Moreover, the clarification of the terminology used in the study is essential. The study is investigating the use of digital mobile site management tools, which in essence are the mobile devices and the cloud software. To avoid the repetition of this term, the author will use similar terms to describe these tools. The terms “mobile digital tools”, “mobile site management applications”, “digital mobile/cloud tools” and “digital tools for automated site data capture”, will all represent the key term stated above, the “digital mobile site management tools”.

# 2. Setting of the problem

This chapter will include the research objective and the research questions, which are generated based on the problem statement and motive elaborated before. In this section a set of questions and sub-questions are described, in order to solve the business problem. At the end of the section, a brief discussion, about the research limitations and assumptions, will be made.

## 2.1 Research objective

As has been discussed before, the main objective of the study is the in-depth investigation of benefits and barriers of digital mobile site management tools implementation and also producing effective recommendations for supporting and boosting the adoption of these applications. Thus, the following research objective is being formulated:

***"To provide an overview to BAM to effectively acknowledge the benefits and implementation barriers of the digital mobile site management tools as well as developing an implementation roadmap to boost the adoption of these tools in the company's future projects"***

## 2.2 Research questions

In order to support the research objectives in collecting and analyzing the information, some main and sub-questions are specified:

1. **How are the digital mobile management tools defined and used in construction project activities?**

    a. How does the existing literature define the digital mobile management tools?
    b. What impact have these tools on the site management processes?
    c. What are the state-of-the-art uses of these tools in certain processes?

The first research question aims to explain in depth the term "digital mobile site tools" as well as describing how these tools can enhance the current construction site management. Moreover, the best uses of those tools in specific processes will be presented, as derived from the existing literature.

2. **What are the main benefits that derive from the use of digital mobile data management tools, from a contractor's perspective?**

The second research question will investigate and prove the benefits realized of using digital tools in construction on-site activities.

3. **What are the main challenges, related to the utilization of digital tools on-site, faced by a large contractor's organization?**

The third research question will investigate the most impactful implementation barriers of this adoption.

4. **What are potential recommendations or strategies needed in order to overcome the implementation barriers?**

The fourth research question is concentrating on the action that BAM as an organization should take to boost the implementation of mobile digital tools on site and overcome the implementation barriers.

5. **How can the possible solutions and recommendations be mapped, in order to be easier implemented by the company?**

    a. What sequence of actions can be followed by a contractor to fully realize the benefits of this implementation?
    b. How this sequence of actions can be logically depicted through an implementation roadmap?

The fifth research question is focusing on developing an implementation roadmap, that it can be exploited by the Royal BAM Group. The aim of this RoadMap is to present a successful path to the company to fully adopt and boost the utilization of site digital applications on BAM's projects.

6. **To what extent can the results of the research contribute to existing literature?**

    a. How accurate and valid are the results deriving from the study?
    b. Are the results applicable for all types of construction companies and projects?

The sixth research question will test and provide information, regarding the applicability and the practicality of the study that was based on BAM's characteristics and context, to different construction companies implementing digital data capturing on-site.

## 2.3 Research limitations

The research's limitations are based on the fact that the methodology is being developed on behalf of the BAM company. Therefore, it will be from a contractor's, and only, point of view and for a company that is dealing with large and complex construction projects. Also the data collection will be limited to a few cases.

## 2.4 Research assumptions

During the start of this thesis is important to establish two different and basic assumptions. The first research assumption is that the goal and objective of this study, which is the development of a methodology to demonstrate the benefits and overcome the barriers, can be reached. The second assumption has to do with the employees and management of BAM. It is assumed that the people of BAM are willing to collaborate and share data in order to meet the study's objective, on the grounds that the research idea was initiated by them.

# 3. Research methodology

This chapter is focusing on giving an overview of the methodology that has been followed for conducting the present research and it has been divided to the research design, the data collection methods and the data analysis.

## 3.1 Research Design

The research has been divided into 6 main phases that correspond directly with the research questions. There is also the preliminary phase that included the introduction, the research questions and the research methodology that will be elaborated in this chapter. The first phase (Chapter 4) will give a thorough explanation of some basic key concepts of construction as well as defining the term “digital mobile management tools”, based on a literature review. Moreover, the use of these tools and their impact on the site management processes, will be further elaborated. The chapter 5 will include the following four phases of the research and answer the main research questions 2, 3, 4 and 5. This chapter is based on interviews, personal observation, meetings and project documentations in order to answer the aforementioned research questions. Finally, Phase 6 is included in the final chapter (6) of this dissertation and includes the final conclusions, contributions, limitations and future research. The following table is depicting the research design adopted in the study:

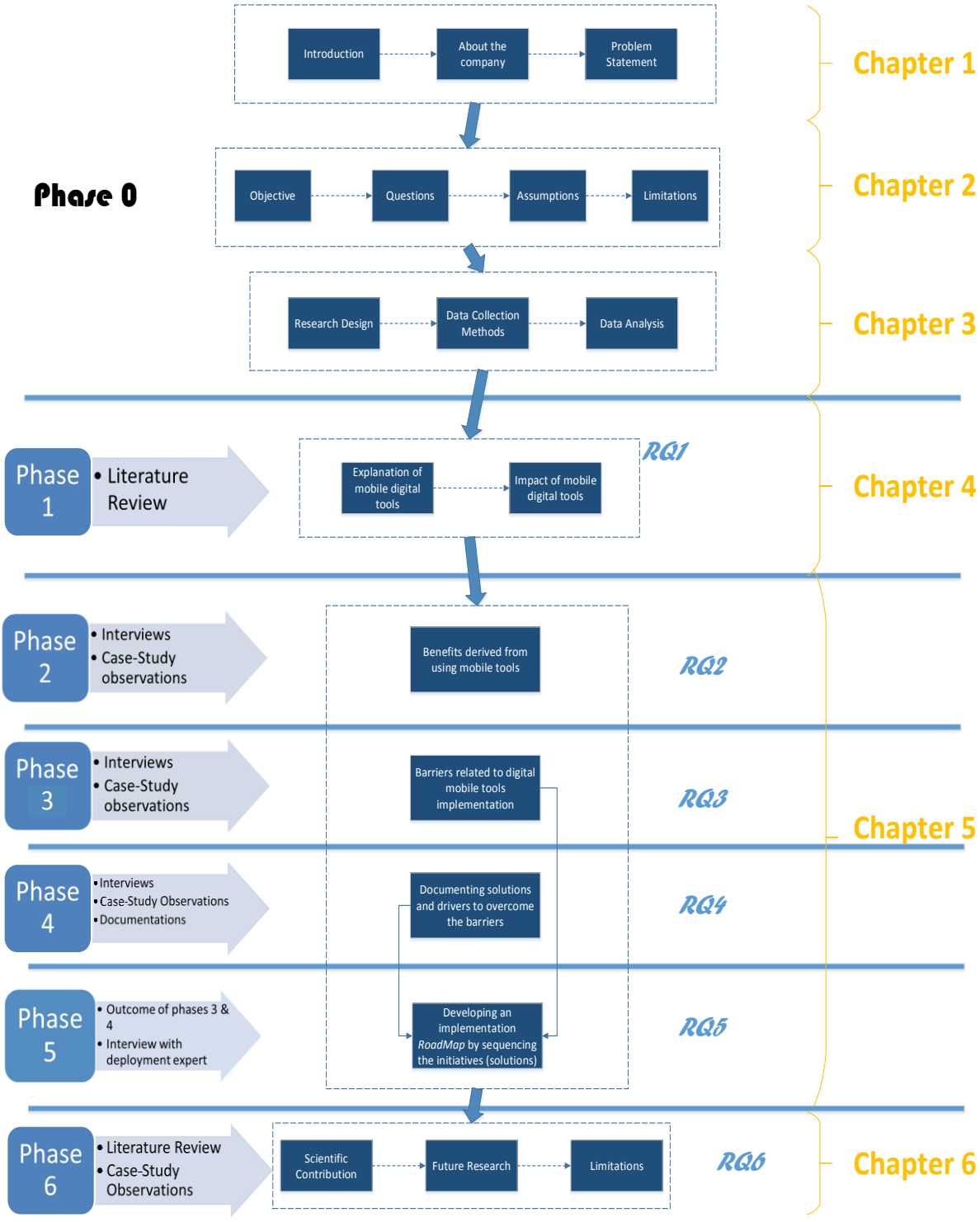



Figure 4- Research Design

## 3.2 Data Collection

A case study approach was selected to assess the implementation of mobile digital construction tools on site. Case study is the most appropriate investigation method for the business benefits of new information technologies, when compared to the formal experiment and other methods (Bakis, 2006). Moreover, case studies are useful when the phenomenon is difficult to be quantified and is one of the best ways for developing a theory and then testing it (Ghauri and Gronhaug, 2010). By comparing different projects in the same company, case studies preserve a stable environment, holding external factors, such as setting and complexity, relatively constant (Barlish, 2012).

More specifically, the research took place in multiple projects of the Royal BAM Group, with duration one month (November 2018). The case-study within the Royal BAM Group, took place in the United Kingdom and involved personal interviews with construction practitioners, field observations and documentations. A complete list of the projects is shown in the figure below.


*Figure 5-Case Study projects*

In this case study, data will be both qualitative and quantitative and will be extracted through literature review, face to face interviews with semi-structured questions, meetings, observations and project documentations.

**A.** The first source of data collection is the *literature review*. According to Saunders et al. (2011), the literature review offers a portrayal and critical analysis of the present condition of knowledge in the subject area. In addition, the literature review defends any new research over criticisms of what has gone before, and explains why the research is important (Khoshgoftar and Osman, 2009).
After reading over 300 sources of information including: journal articles, conference papers, reports, published Master & PhD dissertations and books, there remained 36 sources that had all the necessary information to successfully support the three literature stages that mentioned above. The main concepts that constituted the basis of the search process were the construction site management, digital construction, mobile/cloud management tools, BIM application in construction management and more. The majority of these sources were published within the past five years. The search process, presented in Appendix A, describes in further detail the origin of the theoretical background.

**B.** The *interviews* were conducted in BAM's projects in the United Kingdom and have provided useful qualitative data. The semi-structured interviews include a certain list of questions about the benefits and barriers of adopting mobile site management devices, and were addressed to key-actors of the projects such as BIM managers, project managers, and more importantly to site managers and site engineers. The semi-structured interviews are offering the opportunity to freely probe certain areas and gain a more in-depth analysis on the benefits and barriers. Therefore, interviews can provide high quality and detailed qualitative data. Each of these interviews lasted approximately one hour or less, giving the respondent enough time to elaborate on the digital technology use on-site and the potential benefits and barriers. The duration of the interviews varies depending on the knowledge and available time of the respondents. The respondents were not aware about the exact content of the questions, only about the general topics of the questions, in order to avoid the risk of losing spontaneity, lose data (the duration of silence before the question or the face expression may be meaningful), get rehearsed answers and most importantly not lose the chance of asking new questions that derive from the ongoing conversation.
All the interviews were conducted in a natural setting, and the location was from the different respondents, allowing them to pick a location that is more convenient to them. The interviews were recorded by the author's mobile phone and were semi-automatically transcribed with the use of a web-based software application. Afterwards, all the transcriptions were saved in different Word files. This research involved 35 Interviews with individuals either on construction site or in company offices. The interviewees that were chosen were users of the digital mobile tools, such as site engineers/managers, recipients of the site data, such as project managers and planners, and digital construction managers. The number of the interviewees and their role are depicted in figure 10. Previous studies have shown that this number of interviews is greatly acceptable target for qualitative data collection purposes

(Guest et.al., 2006). By conducting interviews to both, key-actors and key-users, the identification of a potential perceptional gap becomes possible. The detailed set of the questions and can be found in the appendix C.

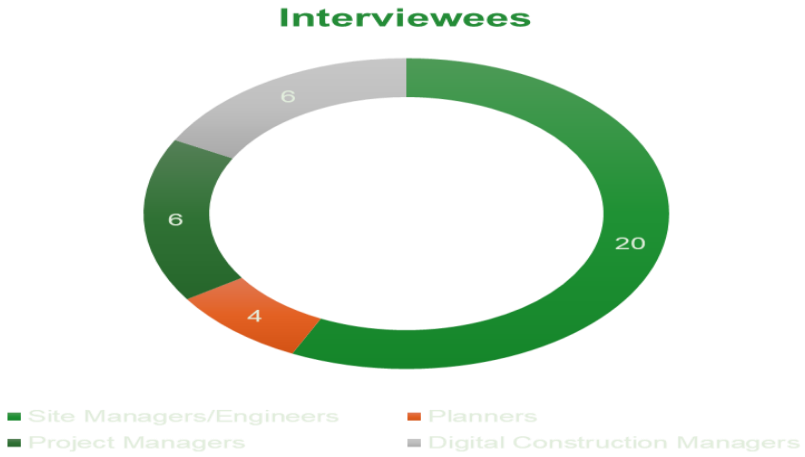



*Figure 6-Role distribution of the interviewees*

**C.** Moreover, an additional data generation process for this stage were the *project documentations* (financial reports). More specifically, a template that includes plenty of metrics to quantify certain benefits that can derive from the use of mobile devices on site was developed by the author. The template was discussed by the author and the project managers of each project. The metrics were referring to the three basic functionalities of the site management, as has been previously elaborated in the theoretical framework, and the respondents were asked to fill in time/cost savings that they identified exclusively from the use of site DC tools. The data analysis (calculations) of those numbers will be conducted from the author. Also, 2 additional projects have also provided the author with tangible calculations about certain processes. The aim of this data collection, is to provide a tangible proof of the benefits that were set earlier on the study and will not provide information about the intangible benefits. The template can be found in the appendix A.

**D.** In general, observational studies are usually conducted by making personal notes on the field based on *observations* of the process of different activities and people's behaviors. Thus, the author could make his own conclusions based on the experience of the hours spent on different projects, that will greatly assist for providing effective recommendations as well as forming the implementation plan.

**E.** The last data collection source will be a short interview with the deployment expert and lead of the BAM's work package 'site data capture', Mark Taylor. This interview will be conducted as a validation to the final outcome of this study and should not be regarded as the main interview within the case-study, as the interviewee will be asked to rank and share his insights on the proposed solutions, and not answering the primary interview questions.

## 3.3 Data Analysis

In this sub-chapter, it will discussed how the different data collection methods were analyzed to support the different phases of this study.

### ***Preliminary Phase & Phase 1)***

### *Literature Review*

As described before, different sources of literature were reviewed by the author and 36 of them were selected to form the research objective and also to answer the first research question. This research involves three stages of the literature review and was analyzed as follows:

a) At an early point of the research, the first stage was conducted to form the preliminary phase. More specifically, a general knowledge of the site management processes of the construction industry was acquired, in order to develop the introduction of this dissertation. These information about the current method of capturing site data and it's inefficiencies, guided the author to form the problem statement. Moreover, this stage also generated the 'object of the study', the digital mobile tools, as an academic suggestion for solving this inefficiency and the main research problem. In general, the first stage was conducted to identify the main problem and form the research aim and objectives.

b) After the aim and objectives were recognized, the second step of the literature review was developed to answer the first research question of the present study. First, a more detailed literature review was conducted on the subject matter to form knowledge regarding the term "digital mobile site management tools". Deriving from this search, additional terms came up that needed to be also elaborated in order to better explain the main term of the study. This additional literature review focused on BIM, Lean Construction and ADCT.
After the establishment and explanation of the term 'mobile digital tools', the impact of these tools was also searched across literature. Giving answers on how these tools are currently utilized in the site management process and also what kind of benefits can offer comparing to the traditional methods.

c) The last stage of literature review contributed to the sixth and last research question of the study. The general knowledge acquired from all the literature review in the previous 2 stages, helped the author to explain how this study contributes and extends the knowledge of the existing literature as well as what is currently missing from both, present and existing literature on this topic, in order to drive the focus of future research.

## ***Phases 2,3 & 4***

### *Interview Results*

Thereafter, the data derived from the interviews was analyzed using thematic analysis. The interviews were the primary data source for executing the phases 2,3 and 4 of this research. Thematic analysis is a method for identifying, analyzing and reporting patterns (themes) within data, by, organizing and describing the data in detail (Smith and Osborn, 2003). This method is different from other analysis methods that are used for describing patterns across qualitative data, such as IPA and Grounded theory. The difference lies to the fact that both of these methods, IPA and grounded theory, seek patterns in the data but are theoretically bounded (Smith and Osborn, 2003). The themes (patterns) that are identified within the data, can be identified in either an inductive or deductive manner. In the inductive approach, the themes are strongly linked to the data themselves (Patton, 1990). In this approach, if the data that was collected specifically via interviews or focus groups, the themes would have limited relation to the questions asked by the interviewer. Thus, inductive analysis is a process of coding the data without trying to fit it into a pre-existing coding frame and is data-driven. On the other hand, the deductive thematic analysis tends to be driven by the author's area of interest and is more analyst-driven. It provides a more detailed analysis of specific aspects of the data but is less rich in description. The strategy that was chosen for this analysis was the deductive thematic analysis, since the researcher is seeking for specific themes that can give more direct answers to the research questions. The specific themes, and generally the way that this method was exploited in the present study, will be discussed below:

The process contains 5 steps (Smith and Osborn, 2003):

**1. Familiarize yourself with your data**

In this phase the researcher went across all the data from the transcribed interviews and by taking notes, and making preliminary ideas for codes to describe the content, has started to become more familiar with the data. The preliminary ideas were referring to the benefits, implementation barriers and potential initiatives for overcoming those barriers. Then the author created 3 different Word files for these 3 basic preliminary ideas.

**2. Assign preliminary codes to your data in order to describe the content**

In the second stage, the researcher assigned codes whenever something interesting was identified in the content of the interviews. The generation of the initial codes, was done by writing pop-up notes in the Word documents. These initial codes were the benefits of using mobile digital management tools, the implementation barriers as well as initiatives to be taken to overcome those barriers. After that, 3 different Word files were created for each of these codes and the selected content of the interviews was added into the appropriate Word file.

**3. Search for patterns or themes in your codes across the different interviews**

After having all the important interview outcome into the 3 Word files (benefits, barriers, solutions), the author started to search for common patterns (themes) separately in these 3 initial codes. This first level of generating patterns were named and written down in an Excel File. Every time a similar pattern was identified in the content, it was added into the Excel.

**4. Reviewing themes**

In the fourth phase of the analysis, the patterns related to the codes from level 1, were reviewed and read through in order to explore if they support the theme, if there are contradictions and if the themes overlap (Level 2). During this stage, the researcher could identify the overlapping themes, narrowing down the number of them in the Excel file. Moreover, the frequency of the repeated themes was gathered, making possible the identification of the most repeated themes by the interviewees. The themes will be depicted in bar charts, in order to give the reader a greater understanding and visualization of the results and their importance.

**5. Naming and defining themes**

In the last stage of the thematic analysis, each of these themes, (different kinds of benefits, barriers and solutions) that were identified from the previous steps will be thorough described and explained in text form.

The completion of the thematic analysis will deliver graphical representation of the top identified benefits, barriers and solutions for adopting the digital mobile tools.

### *Financial Reports*

The financial reports were a secondary source of data collection of this research. The tangible benefits, meaning the cost savings that were already calculated from 2 project managers of the case-study projects, were added in the appendix D.

## ***Phase 5***

### *The implementation Roadmap*

Prior to the development of the RoadMap, it is important at this stage to thoroughly explain the meaning and the use of a RoadMap. A strategic road map is a visualization of what actions are needed to help your company achieve its long-term goals for success. It connects the dots for people in your organization by showing everyone how their everyday actions fit with the company's vision of where it wants to be in the future. A well-designed strategic road map is like a GPS for your business. It not only tells you where you are and the quickest way to get to your destination, it can even shorten the route as less time is wasted with team members trying to figure out things on the go. It's one of the best tools to lift the fog and make your vision clear for everyone on the team. If you want to pinpoint the choices to make today that will affect your future, a good strategic road map can be your ally (Martinuzzi, 2015). In the present study, the

vision and long-term goal of the strategic roadmap is considered the adoption and correct implementation of the digital mobile tools.

For the development of the roadmap certain steps have been followed:

**A. Deciding the type for every suggested action**

Apart from the stages, the type of the proposed action will be established. Three different types of solutions emerge from the 4th step of the thematic analysis of the interviews. These types are: people, technology and process

**B. Deciding the most suitable stage for every suggested action**

The set of actions that derived from the thematic analysis of the interviews will be categorized into four main stages. The stages that will be used for the generation of the roadmap are the preliminary stage, pre-construction stage, construction and post-construction stage. The interviews played a big part on helping the author to understand which phases are more suitable for each action. However, it should be taken into account that this sequence is focusing on the specific interviewees opinions and personal perspective of the author, and is subject to be altered in order to fit better every company's particular situation.

**C. Establishing the most impactful actions (solutions)**

After allocating every of the solutions on the most suitable stage, the impact of each solution will be depicted in the roadmap. To establish the importance (impact) of the proposed actions, three measurement levels have been selected:

**1. High Importance**

Refers to the most important solutions, that will have the biggest impact on overcoming the barriers and boosting the adoption of digital mobile tools.

**2. Medium Importance**

This category include the initiatives that will have a moderate effect on the company's strategy.

**3. Low Importance**

The third category included the least important actions, that the company should not exceedingly focus on.

For determining which of the solutions can be considered high, medium or low importance, the total number of solutions is subdivided into 3 equal subdivisions. Thus, the solutions that gathered the less responses will be considered as 'low importance', the solutions with medium amount of responses will be considered as 'medium importance' and the solutions with the highest frequency will be considered as 'high importance'. The results of the interviews (bar-chart) will be used to calculate the amount of responses for every potential solution.

**D. Visualizing the solutions in a RoadMap**

After the establishment of the stage, type and importance of the solutions, they will be presented in a roadmap. The roadmap will have in total three dimensions (stage, type, importance) and the two dimensions will be presented into X and Y axis, respectively. The third dimension (importance) will be depicted by the use of different colors, for every different level of importance, in each of the solution boxes. The RoadMap will be created with the use of Microsoft Excel.

After the completion of these steps and the development of the RoadMap, a possible validation will be discussed. For the validation of this Roadmap, an additional interview will be conducted with the deployment vendor manager of Royal BAM, Mark Taylor. Hence, the insights from the decision-maker of the deployment and strategy regarding the digital mobile tools in the company, can provide a solid reflection on the case-study results.

## ***Phase 6*** **Scientific contribution, limitations and future research**

The outcome of all the data analysis conducted in the previous phases will form and be used as input in this phase.

## 3.4 Elements of the research methodology

**Reliability and validity**

According to Hartmann (2017), reliability ensures that if a later investigator followed the same procedure as described for our research, the later investigator arrives at the same findings and conclusions. The case study researcher creates a plan that incorporates a variety of data gathering methods to answer the questions. When the researcher obtains similar findings through two different methods, in our case the case studies and literature review, that information is considered more trustworthy or credible. In this study, the interview data will symbolize the qualitative approach to the study, along with the field observations, whereas the project reports and the author's template will represent the quantitative approach. This means that a mixed-method approach will be used in this study. By using the mixed method approach, it will allow the interview results to complement and uphold the findings of the results from the questionnaires and literature. This concurrent triangulation increases the validity and trustworthiness of the findings.

**Time horizon**

The data collection will be conducted in a cross-sectional approach. The cross-sectional approach is observational, meaning that the researchers record information about their subjects without manipulating the study environment. For this thesis, qualitative and quantitative data will be acquired from different groups with different roles for accomplishing the research objectives.

**Extent of researcher interference and study-setting**

For both the survey and the multiple-case study, the extent of interference by the researcher will be minimal. Due to the fact, this study is a correlational study, the case-study will be conducted in a natural environment with minimal interference by the researcher with the normal flow of events. Furthermore, correlational studies are conducted in non-contrived settings. All the studies that are conducted in non-contrived settings, can also be described as field studies.

**Unit of analysis**

The unit of analysis can be described as the level of aggregation of the data collected during the subsequent data analysis stage. The unit of analysis will be the individual perspectives on project benefits that will be aggregated to organizational benefits (BAM level). In our research, we are seeking for different opinions of the employees of the Royal BAM group. The different perspectives that will derive from the BIM key-actors and key-users, and from actual tool users and non-users (recipients of information), will give us a more holistic view of the situation, a stronger proof of the benefits and a greater variety of potential solutions of the problem.

# 4. Digital Technology Background

In the first part of this chapter, the key innovative processes of BIM and ADCT will be elaborated. Thereafter, an analysis will be conducted regarding the use of mobile/cloud digital construction tools and their use in construction projects. The final part of the literature review will discuss the use of digital construction in construction management. During the pre-construction stage, which is prevalent the use of BIM, but also during the on-site activities (site management). The site management is the focus of the study, as the use of mobile site digital tools can be proven extremely beneficial for increasing the efficiency and productivity levels of the project team.

## 4.1 Key concepts

The innovative processes of BIM, lean construction and ADCT are complementary, as they all seek to significantly improve project execution performance through reduced waste, reduction of unnecessary process stages, concurrent design to reduce errors and rework and shortened cycle durations (Eastman, 2011). BIM provides a quick platform for quick communication and allows clients to assess the impact of last minute changes. Automated Data Collection Technologies are creating the means for the rapid communication within the project team and also the client (Moran, 2012). These processes can be enabled by digital mobile management tools, cloud computing and mobile devices, recently introduced in the construction industry (Berg, P. et al. 2014).

### 4.1.1 Building Information Modelling (BIM)

What is BIM?

As it has already stated in this paper, there is not a unique and a single widely-accepted definition of the term 'BIM', as its definition varies according to the scope, need and use of the individual or organization. The term BIM represents different things to different people, which include tools, people information management and process (Hossain et al., 2013). For some is a modern technology that can easily control and check a model, whilst for others is an enhanced process for the design, construction and maintenance stage of the project. Previous studies were focusing on developing or choosing the most suitable definition of BIM. Instead of trying to choose a generic definition from the existing literature, a holistic description can provide a wider and more accurate understanding of the term 'BIM' to the reader. The 'holistic' nature of the description followed in this sub-chapter will ensure that everybody can develop the same understanding and capture the whole picture of BIM.

The core function of BIM is the capability to insert and connect valuable data in a 3D model, which was the initial reason that brought BIM into the industry's scene. These models bear all the relevant information and geometrical data of the building. Through time, the projects became more complex, and the need for enhanced management and flow of information became more urgent. A simple visualization of the geometrical data of the building is no longer enough to deal with the contemporary requirements of the AEC industry. BIM provides important project information to the 3D model, that specifies every aspect that can have an impact on the budget

and schedule at any stage of the construction. In other words, BIM is a 3D building model, that entails the visualization of the geometrical data, in order to successfully simulate and predict the whole building behavior of the building process prior to the actual start of the construction. The derived database, goes beyond the engineering and designing boundaries, to a project tool that is able to coordinate, to track and monitor the construction progress, and to estimate the project cost at any point of the construction process (Eastman, 2011). Regardless that this information is mainly exploited during the design and construction phase, it can also be exploited throughout the post-construction and operation stage of the building, offering important benefits. The information that is managed and dispersed during a building's whole lifecycle is represented by 3D objects, such as building components but also workspaces (Salih, 2011). From a contractor's perspective, BIM intends to increase the level of communication and collaboration. The terms collaboration and communication are becoming strongly linked with BIM, among all the disciplines engaged in a project, not only for designers, engineers but also for facility managers, owners etc. According to what have stated as far, it is clear that BIM is not only about using 3D intelligent models, but also applying changes in the process and the workflows.
BIM can be used both as a noun and as a verb. As a noun, 'Building Information Model', means the 3D model that contains all the information that is linked to the objects. For example, a door that exists in a Building Information Model is more than a schematic representation of a door, but it also contains information for its manufacturing, installation, finishing work and maintenance. As a result, all the different people that are responsible for each of these aforementioned tasks, can view the desired information without applying changes in the overall database (Chelson, 2010). Whereas, when used as a verb, it is referring to the act of simulating real-life tasks of a construction process (Eastman, 2011).

**BIM as a Software**

Taking into account, the boom in the utilization of BIM within the construction companies, it is only logical that there is a vast number of BIM software developers. The main focus for the software developers used to be the 'modeling software', and generally the software that is connected with the design phase of the project. Many of the technology companies were investing on software programs that bring together a 3D model with geometrical, budgeting and planning information. The reason behind this is that the software companies get immediate value from these design-focused tools. However, the software approach has sifted the past years to tools that can help to coordinate as well as automating the information exchange from the 3D models to contractor's aspects such as quality control, scheduling, and monitoring (Hergunsel, 2011).

**BIM as a Process**

The BIM process is the manner that construction companies can achieve time and cost savings in their projects. Given the capability to plan and visualize, anticipated and costly problems before they even occur, they are in a position to avoid huge and avoidable project expenditures. The BIM process can drastically influence all aspects of a project and can be categorized into 4 main sub-processes:

- The sub-processes enabling the owner to develop an accurate understanding of the project design
- The sub-processes enabling the design, development and analysis of the project
- The sub-processes enabling the management of the construction of the project
- The sub-processes that are related to the management of the operations of the project after its completion and during its actual use. (McGraw-Hill, 2009)

According to Smith (2012), there is no ideal process for BIM. The BIM process, and consequently the sub-processes, vary accordingly to the market needs, the workflows, the goals and also the organization's strategy. However, there are some generic principles and goals that should be included in every BIM implementation and process. The implementation of a BIM process is a strategical decision for an organization and not only a design or engineering solution. BIM is a new technology aims to improve the most important aspects of an organization such as the communication within the company but also within its supply chain, the quality of the product, the decision-making, the reduction of costs and time in the whole life-cycle of a building (Smith, 2012). The challenge for an organization for fully engaging an effective and beneficial BIM implementation, is depending among others on the education of its employees. Such a BIM implementation strategy, should be accompanied by education and training. The difference between education and training is that training teaches people how to perform certain tasks, whereas education teaches people how to think and how to enhance the business processes from an organizational point of view. Hence, it can be stated that the software and the training are only the 'tip of the iceberg' for an effective BIM implementation, and the education and culture change can be considered as the 'game-changer' (Smith, 2012).

### 4.1.2 Automated Data Collection Technologies

Automated data collection technologies (ADCT) in construction can be used for comparing the actual conditions against the baseline conditions. The human error is an aspect that cannot be overlooked or totally eliminated, and this technology is playing a vital role in catching these unexpected errors. Several tools are currently being developed in the construction industry to support field verification, track installation and monitor progress, such as (Eastman *et al.,* 2011):

- **Laser scanning technologies**: Contractors can use laser technologies, such as laser measurement devices that report data directly to a BIM tool, to verify that concrete pours are situated in exactly the correct location or that columns are properly located. Laser scanning can also be used effectively for rehabilitation work and capturing as-built construction details.
- **Machine-guidance technologies**: Earthwork contractors can use machine-guided equipment to guide and verify grading and excavation activities driven by dimensions extracted from a BIM.
- **GPS technologies**: Rapid advances in GPS and the availability of mobile GPS devices offer contractors the ability to link the building model to global-positioning-systems to verify locations.
- **RFID Tags**: Radio Frequency Identification tags can support the tracking of component delivery and installation onsite. BIM components that include references to RFID tags can automatically update with links to field scanning devices and provide contractors with rapid feedback on field progress and installation.
- **Mobile data collection devices (Tablet PCs):** With the mobility of tablet PCs the information can be collected, updated and accessed automatically by the users where and when needed.

For ADCT's to be successful, certain requirements must be met. Minimum effort for data input from the users should be enough to accurately identify issues. All the input from the ADCT systems should be stored centrally and connected with the BIM model for project control purposes (Eastman et al, 2011). These tools are developed for supporting and realizing the lean principles in a construction project. Reduction of waste and enhancing the visibility of the supply chain network, time reductions, labor reductions and ensuring the accurate delivery of materials and equipment.

## 4.2 Digital Mobile Site Management tools -Object of Study

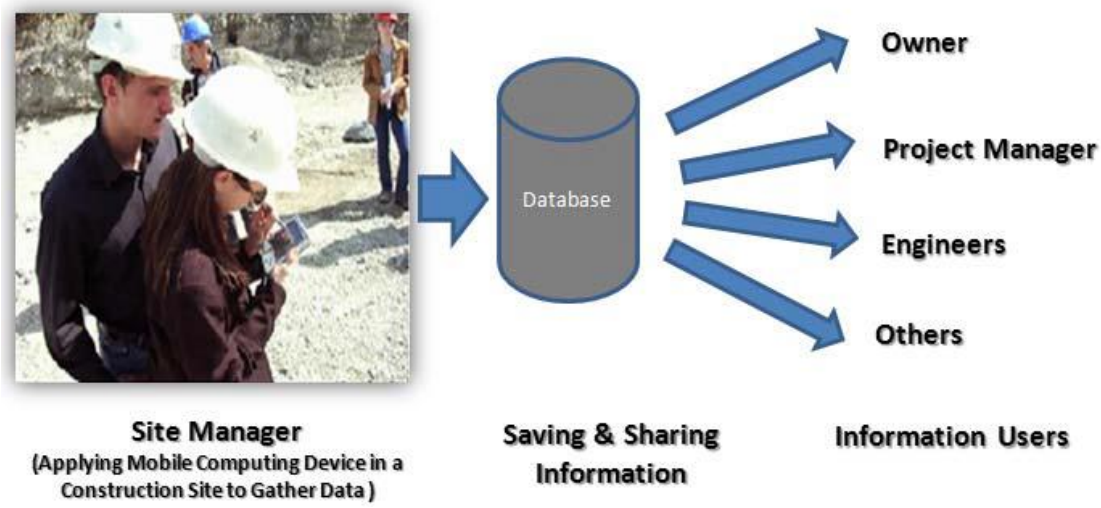



*Figure 7: Mobile/Cloud-based Information Management Flow*

Digital mobile site data management tools are beginning to bridge the divide between office and site activities by leveraging the advances in mobile devices, wireless connections, software and BIM (Sawyer, 2010. The use of mobile digital tools was only recently introduced to construction sites and contained limited and primitive features. The invention of iPads and smartphones is completely changing the landscape of the modern-day construction project, regarding the way the information is being accessed and how is utilized and shared (Hardin, 2017). According to Harstad (2015), "In construction, one of the biggest developments in project management is the integration of mobile technology. The tools that help collaborate and eliminate bottlenecks in the three phases of construction-planning, designing and building are rooted in tablets, smartphones and mobile intelligent hotspots". The mobile technology enables project stakeholders and project teams to collaborate and communicate real-time, creating room for feedback and for the information to effectively flow from the field to the office. Nowadays, more and more construction companies are accepting the use of mobile devices and the software developers are enriching the mobile device use with new applications. As has been stated earlier, construction industry is plagued by low productivity levels, inefficiencies and, ultimately, extremely low profit-margins. The integration of the mobile digital tools may be perhaps the answer to the industry problems, as many companies have begun to comprehend the benefits of these technologies and also open the way for future adopters. The most efficient way for a construction project team to effectively manage site information is to retrieve and capture this information at the specific location and the time they need it (Chen & Kamara, 2008). Rather a difficult task for the traditional paper-based methods. The main-type of information that exists on-site among the construction personnel is paper-based, posing a major constraint for an effective and real-time communication. The mobile/cloud technology promises to offer higher levels of cooperation, enhanced accessibility of project data and site images, by simply linking the mobile devices with a cloud platform. The real time cloud platform used through the mobile devices is giving the

chance to the users to communicate virtually, to view and make responses to site issues directly from their mobile tools (Abanda et al., 2018).

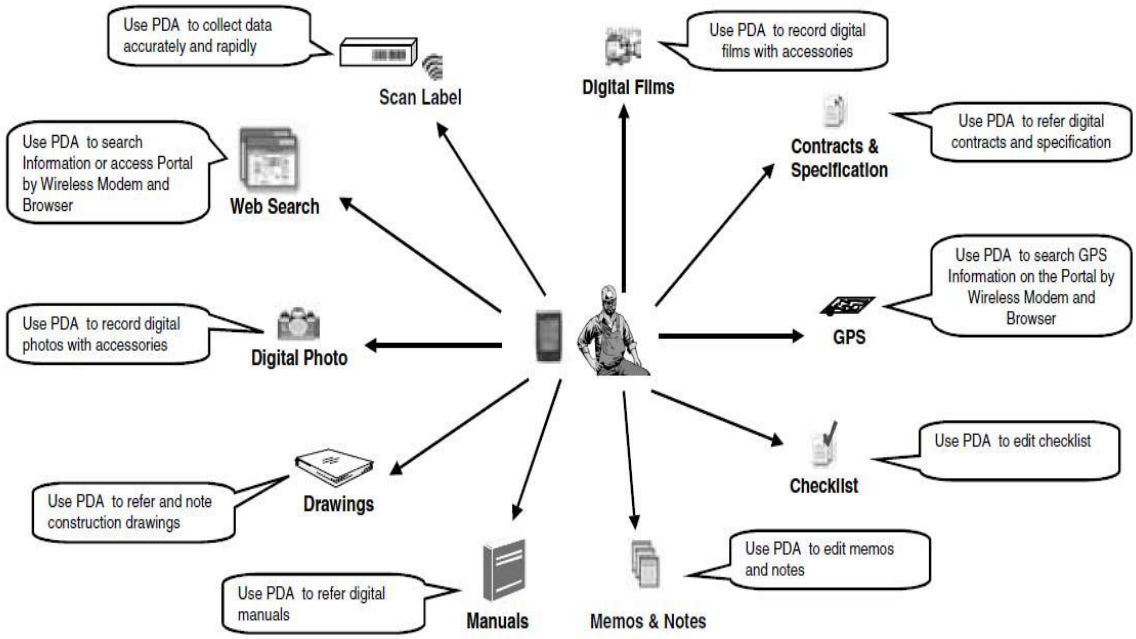



*Figure 8-Application of Mobile in Construction Sites*

Rebolj and Manzel (2004) have categorized the concept of mobile computing/mobile tools. These categories are: computers, networks and mobile applications. Computers include the hardware such as phones, tablets and wearable computers. Networks consists of all types of wireless networks. Mobile applications are the key means that bridge the gap of the computers and networks, for supporting the users work processes and increase the efficiency and communication in a project. Regarding the mobile applications, there are also three different categories (Sattineni and Schmidt, 2015):

- Mobile BIM/CAD applications for interacting with drawings at the construction site
- Data Capture applications for managing on-site information
- Project management applications for monitoring and controlling the construction process at the construction site

The use of mobile devices has entered the project sites all over the world, and will continue to spread as companies finding ways to overcome the related implementation barriers such as the need of resources and re-organization of strategies and processes (Sattineni and Schmidt, 2015). Since the use of tablets and the range of applications have increased the last 10 years, it is therefore important for the literature to catch up. The literature has dynamically starting to investigate this topic the last 2-3 years, and it of high importance to continue in order to ensure that the development is heading to the right direction.

## 4.3 The role of 'Digital Construction' in Construction Management

The digital boom over the last decade has changed the landscape for technology companies, especially because of the BIM, urging them to create digital construction tools. Straying from the path of creating applications and tools for the design because of the immediate value, the software industry is now focusing on digital applications that can create value for the contractor. These tools are striving on finding ways to enhance the communication and coordination on the project, to automate and improve the information flow and to better manage the construction process. In essence, the construction digital tools, as stated earlier, are meant to bridge the gap between the design and the construction.

Building Information Modelling (BIM) is changing the way that construction management is conducted (Eastman *et. al*., 2011). The main power of BIM in the construction management is the ability to pull out information from the 3D model, and turn it into detailed workflows and processes, such as estimating, scheduling and logistics. BIM in construction management comes in different shapes and sizes, regarding the company or the project itself. In some cases, BIM is adopted only during the pre-construction phase; the administration phase of the project is then managed with the traditional methods. In other cases, BIM processes are being utilized during the construction stage, but as the project processes, people tend to switch to traditional practices as it quite difficult to change their habits. Hence, the potential growth of BIM and other innovative digital techniques is hindered. The solution to that is to gradually adopt the new practices until they become habit and selectively use the practices that better fit their tasks. As the projects become more complicated and difficult to manage, new practices will be introduced by the software developers, that will be more advanced and user-friendly in order to meet the rising demands of the industry.

What digital can actually offer to the construction management? By embracing digital technology, contractors can increase the productivity levels, reducing rework, increase coordination and providing higher quality product to the client. The means and the techniques for achieving these benefits will be extensively discussed in this dissertation. However, there are drawbacks, and in some occasions, issues should be dealt in the traditional way. BIM is not a panacea, or better is yet to be a panacea. Therefore, this dissertation is focusing not only in BIM, but on the digital tools as a whole in order to increase the efficiency and productivity.

In the rest of this chapter, the author will describe the applications of digital tools, for the basic functionalities of a project. The use of digital technology in construction management will be analyzed in two stages, the pre-construction activities and the on-site activities. Despite the fact that the main goal of the research is to investigate the use of digital mobile management tools on-site, it will be of a high value to present in short the use of digital tools prior to the start of the construction. There is a thin line that defines these 2 set of activities, by establishing concrete explanations and justify the reasons of this separation, the reader could acquire deeper insight of the study's main objective. Furthermore, the expected benefits that derive from using digital tools will be identified as well as the main factors that hinder the adoption and implementation of mobile digital tools on site.

## 4.4 Digitizing the Pre-Construction

### Scheduling

Scheduling is an integral of the planning and one of the main tasks of the construction manager (planner), before the start of the construction. The traditional method of scheduling the construction process, is based on the past performance experience without any direct link between the design and the schedule. In the early design stage the construction manager generates the schedule in Gannt charts based on assumptions, as the project information are limited. However, this method slightly connects an activity with a building component, without linking specific drawings, specifications with the schedule. BIM can play a massive role to enhance the scheduling the scheduling process. The 3D model can be directly linked to a construction schedule using the 4D scheduling (Eastman, 2011). Through the use of BIM tools, such as Navisworks and Synchro, the elements and components of the design can be animated, making the process of updating and modifying the schedule much faster and appealing (Hardin, 2015). The project planner, through the aid of 4D, has the capability to animate and visualize the whole construction process that can provide information about the building site, at any given time.

### Quantity Take-off and Cost Estimating

The majority of BIM tools offer an automated estimation for the quantities of components, materials, area and volume of spaces, during the pre-construction stage. One of the BIM basic uses, the BIM Model-Estimating, known as BIM 5D can automatically extract spatial data and quantities from the BIM model, ensuring that the quantity take-off is updated to the latest model modifications and resulting to considerable time-savings when compared to the traditional manual 2D estimation (Moran, 2012).

### Clash Detection

The Model-Based Coordination, the first use of BIM, was the “game-changer” as it has provided the contractor the ability to use a single 3D model for all the construction documents, reducing dramatically the design errors and change orders of the 2D traditional way. BIM software tools, such as Navisworks, can virtually run together systems from different disciplines and identify the clashes between them. Every element in the model can be checked against another, element or set of elements. As the clashes are identified during the design stage, there are severe time and cost savings in the construction process and legal disputes are minimized(Eastman, 2011).

### Prefabrication

Prefabrication is about constructing building components off-site and then locating them to the correct place on-site. Through prefabrication can be achieved dramatic time and cost savings as well as significant quality improvements. A key aspect of BIM is that can enable the use of prefab components, due to the fact that contains parametric modeling information, many fabricators can easily build their components.

## 4.5 Digitizing the construction site-management

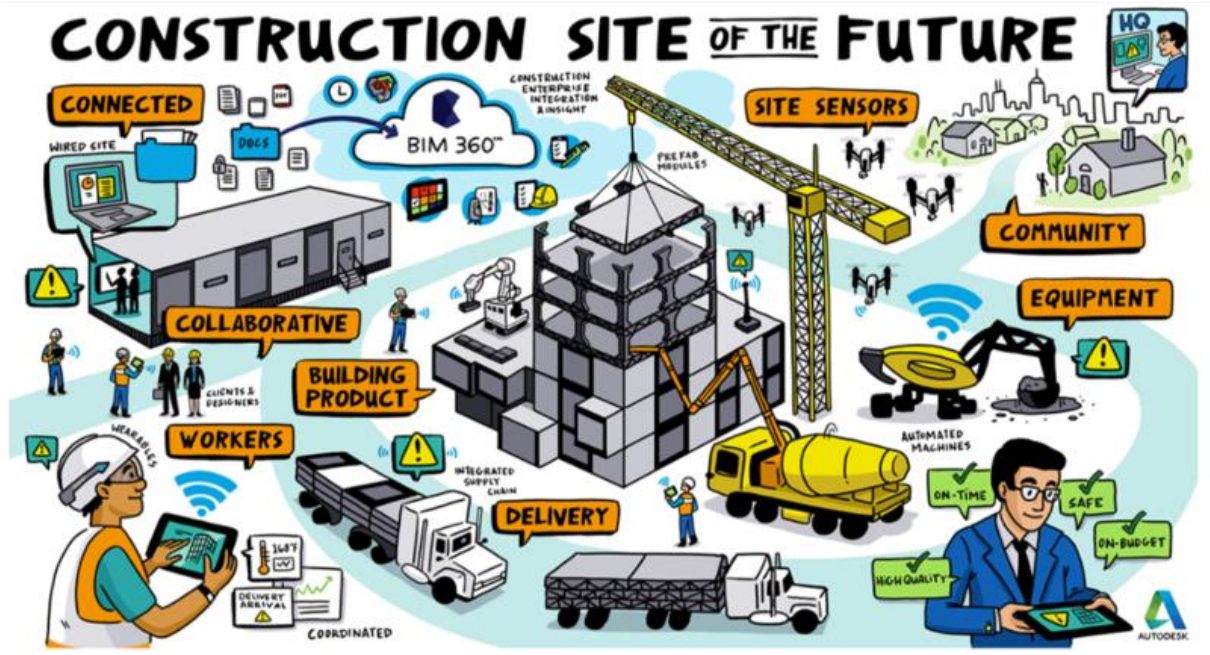



*Figure 9- Construction site of the future*

Most academic research relating to digital construction, mainly BIM use, has been based around design, pre-construction, planning and there has been far less effort to investigate digital tools to support production management on site. A connection from site to access digital systems needs to be established in order for the information flow to exist (Sacks, 2010). BIM has been successfully exploited during the design and pre-construction phase of the project, as has been previously elaborated. However, the vast majority of extra costs and reworks are happening out in the field. Contrary to the misconception that digital tools do not work in the field, taking also into account the effort and initial investment needed to use in the field, should be stated that digital tools do work in the field as has been proven by previous research studies and potentially by the present study. There is plenty of room for improvement and smoother interoperability between field systems and tools, but a great opportunity is overlooked by contractors who choose not to use today's technologies and leverage them to some extent on the construction site.

In this study, the use of digital technology during the construction stage will be defined as the digital construction tools that are used to automate the site activities, by automatically record and share field data. Digital construction tools are defined all the BIM related tools, the mobile devices such as smartphones and tablet computers as well as the cloud-based applications that are used to digitally share the information extracted from the field among the project team members. The proper software is necessary for mobile tools to provide benefits. A tablet without the proper software will be used much like a laptop in the field.

## Site Management Processes

The site management processes refer to the processes taking place on site to verify the construction. The site management has been divided into 3 basic functionalities (processes):

A. **Progress Control**

B. **Quality Control**

C. **Site Coordination**

According to Hardin (2015), the use of digital tools on-site activities has great impact on these 3 site management processes. More specifically, the progress control, the quality control and the site coordination are tasks that are executed by the project team, for example the project manager, the planner, the digital construction manager, the site engineers and the superintends. In this chapter, the state-of-art digital processes as well as the derived benefits will be presented, as extracted from the literature review. The benefits that will emerge from each of these processes, will be used to form a measuring template of the tangible benefits and a potential calculation of a project's ROI. The template can be found in the appendix B.

### A. Progress Control

The BIM scheduling and planning during the pre-construction stages cannot guarantee the success of the project, if not combined with on-site verification of the tasks statuses. Traditionally, the flow of information from the field to the office for tracking the project progress is made manually which is a form of waste (Pozuelo, 2017). The master schedule is usually developed in "non-flexible" programs, such as Primavera and Microsoft Project, that become inaccurate after the first project delay. Hence, there is a need for field-mobile-enabled feedback tools to capture the construction progress (Hardin, 2015). Contractors are now beginning to realize the value of a feedback loop between the field and the office in order to provide value planning. Linking the field tasks with the initial schedule can reduce the efforts of the project teams to acquire and share schedule data. The common (non-BIM) practices for controlling and tracking the progress are the Gantt Charts, Time Location Charts and the S-Curves, however these tools may provide an acceptable representation of performance, delays and project dates but they are not fully connected with the tasks, relying on educated guesses from the project team. It is important to have a flow in the daily progress tasks, that is not a strength of the current practices. For example, the traditional CPM method is effective for analyzing milestones, creating a logical schedule and for defining the critical path, without being able to provide predictability for the future site activities. BIM, through its 4D capabilities, can successfully extract progress information from the field and store into a shared BIM file for the entire team to view. Thus, this information can be updated from the site and then be viewed by the planning team in order to update their models and the master schedule. Tablet applications on the market, such as Synchro site, intend to close the gap between the office and the on-site activities. Via cloud service, the mobile applications

are connected with the office and allow for real-time update of the different tasks, making data reachable to all the people involved in the project.

More specifically, through tablets the progress tracking can now be implemented in an automated manner. In the beginning, the schedule of the project should be linked with the model according to the construction phases, the mandatory milestones and the associated purchasing processes, among others. The 4D model is inserted into tablet application and the site engineers can track the progress of the element by clicking on it and then update its status while being on site, minimizing the time spent on non-value tasks and allowing them the time to focus on more value-added activities. The product also enables inspections regarding the tracking of delays in activities through activity statuses. The on-site inspector selects the elements whose activity status does not adhere to the original project schedule (either earlier start or delayed) and changes its status on the tablet. These modifications in status on Synchro Site are synchronized into the cloud, the original schedule is automatically modified to compensate for these alterations in time and recalculated the critical path.

Traditionally, the site engineers are carrying paper 2D drawings and blueprints while being on site. Then, by looking on these paper drawings, they mark the status of the objects or they take photographs, before going back to the site office, translate the information and fill in the daily progress. Moreover, the on-site digital tracking can enhance the information flow with the planning department. As the site engineers, have updated the 4D model while being on-site, the planner can input the 4D model data into the master schedule, which is usually made by Primavera or MS Project. The schedule data that is gathered through the mobile device on site, is linked to the elements in the model, and the elements are also linked with the planned activities in the master schedule. This digital process is smoothing the tracking of the progress and is saving valuable time and effort from both the site engineers and the planners (Renzi, 2018).

Apart from that, the field progress tracking with mobile tools can also improve the level of understanding what specific elements need to be completed first in order to allow for the successor activities to finish. If one activity requires a certain space in order to be completed, the automated field update from the field, can provide the most effective sequence.

As derived from the literature review, the benefits of using mobile to track the progress of construction activities are the shown in the following table:

Table 1-Benefits of progress control

| Benefits of using mobile tools for tracking the construction progress |
|---|
| · Real-time update of the information, enabling for better decision-making |
| · Enhanced monitoring and documentation of the progress |
| · Increased feasibility of the planned activities |
| · Reduction in time spent from the site engineers comparing to traditional tracking methods |
| · Enhanced communication with the owner |
| · Reduction in time spent by planners to update the master schedule |
| · Reduction in delays |
| · Reduction in time to generate the productivity level reports |
| · Reduction in reworks due to schedule conflicts |
| · Improved accuracy of the master schedule |
| · Reduction in costs for printing and delivering documents |
| · Reduction in rework due to communication about the task scope, resources and methods |
| · Allocate resources on more important activities to compensate for productivity losses |

**B. Quality Control**

During the construction phase, there is always the possibility of a human error. Regardless, of the degree that digital construction can have on the correct installation of systems on the field, there will be always the risk of a worker to install a system incorrectly. However, BIM when is integrated with the Automated Data Collection Technologies (ADCT), can have a huge impact on the speed of discovering and resolving those issues. A mobile component of a quality management system can streamline the process to reduce man hours and risk while increasing profit, quality, and transparency. This increases value not only for the contractor, but also for the owner and subcontractors. Implementing a quality management system that has mobile field capabilities can benefit a company substantially (Gleason et. al, 2014). In a typical construction project, when an issue appears it has to be decided whether is an issue of the subcontractor, the main contractor or the issue is out of both scope and need to be resolved from the design team. The process starts when the subcontractor has completed his task and notifies the superintendent to begin the inspection for potential issues or non-conformities according to the contract document and scope. The superintendent writes down on paper the potential and then goes back in the office to check his notes and compare. While in the office, he transcribes the issues from paper to digital. The issue is manually stored to a shared project database and then is sent out to the project members as RFI's, bouncing back and forth until it is decided who is responsible for giving the answer. Hence, creating severe delays, inefficiencies and disputes among the project members. Due to this inefficiency of the traditional method, the construction industry has switched its focus to technology and mobile tools, that can make the process more lean and improve the information flow among the team. Once at the jobsite, the user does not have to return to the

office to update the process or report an issue; everything can be done immediately with an internet capable device. The user can use a checklist for work tasks and a punch list for tracking issues, or receive/create a note on the plan, regardless of whether he is in the office or at the site. With these software packages in use, the sub-contractors, general contractor, engineers, architects, or owner can save time on meetings and updating processes. With the interactive feature of a mobile device, any party in a project is allowed to get live updates from the other party, and can quickly reply back to solve the problem. The owner can easily stay updated with either general or detailed project statuses by simply accessing the project database with the account that is provided. The accessibility will help the company stay ahead of the issues that may arise, and easily manage multiple projects. Furthermore, owners will have more control in what they are investing in.

Table 2-Benefits of using mobile tools for controlling the quality

| Benefits of using mobile digital tools for controlling the quality |
|---|
| · Reduction in time for identifying the issue |
| · Reduction in time for reporting and sharing the issue |
| · Reduction in time for solving the identified issue |
| · Enabling the contractor to use more accurate sources for avoiding claims and disputes |
| · Avoid costs deriving from claims |
| · Avoid costs from unnecessary work to identify the root-cause of the issue |
| · Reduction in the times travelling from the office and back |
| · Saved time from update-meetings |
| · Easy accessibility of the issues and their causes by every member at any time |
| · Minimizing the possibility of losing inspection since all information is stored in the central repository |
| · Site engineers can spend more time in the field |
| · Having saved data for evaluating a subcontractor's capacity |
| · The information stored can be searchable and retrievable years after the completion |
| · Reduction of printing costs |

**C. Site-Coordination**

The site-coordination refers to the material management on-site, the tracking of the equipment and the on-site safety (Hardin, 2015). The site-coordination is based on the logistics plan that is developed before the commence of the construction. The logistics plan is usually printed and posted on the project's site office, making possible for everyone to visualize the site, the material's location and hazardous areas. However, the logistics plan is a static image and especially in complicated projects the variations of the schedule and the areas are constantly changing. Hence, a constant update of the logistics plan is required for an enhanced material and equipment tracking and for a safer site. By linking the mobile tools with the use of electronic identification (RFID, QR codes) that are linked to every piece of material and equipment, it becomes possible to coordinate and keep track of the site at any time (Fernandes, 2013). The RFID tags that are placed on every component, can be scanned with handheld computers providing all the corresponding details (status, checklists, etc) in the linked BIM software. Furthermore, the materials and construction equipment such as cranes, bulldozers can also be scanned through

GPS systems. In particular, this technology can give all the necessary information to the site supervisors and construction managers ensuring an accurate inspection and verification of the materials and equipment. RFID mobile technologies can also assist in recovering misplaced and stolen materials on construction sites. During the economic downfall in the U.S.A., materials and equipment that worth 1 billion dollars were stolen from sites (Bedard, 2014). Moreover, depending on the project, some have large "lay-down" areas that makes the delivery time of the materials not a serious issue. In other projects however, the materials need to be delivered at a specific time to maintain the correct flow of the scheduled tasks. Following the Lean principles, the JIT (Just-In-Time) approach that is achieved with the RFID technology, can offer higher accuracy and considerable waste reduction (Hardin, 2015). Regarding the equipment tracking, this mobile technology can play a big role. Construction managers can use mobile devices to input and collect information about particular pieces of equipment. Many equipment tracking applications, such as Verizon's Networkfleet and ToolWatch are available that allow a construction manager to scan a piece of large equipment to access the make and model, load capacities, operations manual, maintenance records, and licensed operators as well as engine diagnostics and fuel consumption (Hardin, 2015). The link of the inventory to the BIM model and database can also prove useful in the final close-out, as the accurate field data can be used for a successful facility management system (Fernandes, 2013).

Table 3-Benefits of using mobile technology for site-coordination

| Benefits of using mobile technology for site-coordination |
|---|
| · Costs saved on fuel by unnecessary movements of vehicles |
| · Costs saved of over-ordering materials required for an element |
| · Time saved on contacting suppliers to verify quantities and delivery of materials |
| · Time saved for disposing/storing unnecessary materials |
| · Costs saved for disposing/storing unnecessary materials |
| · Time lost due to late materials delivery |
| · Reduction in time for inspecting and identifying materials and equipment |
| · Real-time information regarding the status of materials and equipment |
| · Reduction in costs for recovery of stolen materials |
| · Enabling on-time delivery of materials |
| · Ensuring the good condition of equipment |
| · Reduction in idle hours due to malfunctioning equipment |
| · Reduction in delayed tasks due to late delivery of materials |
| · Better selling out price of equipment since it has all the maintenance information stored |

# 5. Results & Analysis

In the previous chapter, the digital technology background was established about the explanation of term 'digital mobile management tools' and how these tools can be used to successfully digitalize the construction site management. Moreover, some basic site management processes were identified, the progress control, the quality control and the site coordination, along with their proposed benefits as derived from literature. The digital technology background has played an important role on this chapter, since it was utilized during the interview process as a basis for the generation of the questions, but also providing the interviewees a reference structure to address the benefits and barriers. However, the respondents were asked to answer without any restriction, in order to avoid any biased conclusions.

In this chapter, the benefits and the barriers, that derived from the case-study in BAM's projects, while using mobile digital tools, will be analyzed and discussed further. More specific, in the sub-chapter 5.1, the benefits that the interviewees identified while utilizing the digital mobile tools to capture site data will be presented and elaborated. The following sub-chapter (5.2) includes a thorough investigation of the problems as well as the reasons that project-based employees choose not to use the digital tools. In the sub-chapter 5.3, specific solutions and sound recommendations to the company will be provided. These solutions derived from the interviews (thematic analysis) but also from field observations of the author. These solutions will be categorized by stage and type, targeting an easier comprehension of the company, other construction companies that are interested to adopt the digital site data management as well as other potential readers. In the final sub-chapter, the main deliverable of the study, the Roadmap, will be presented, discussed and validated from the output of an additional interview with the digital construction vendor manager of the Royal BAM.

## 5.1 Identified Benefits

This sub-chapter aims to answer the research question 2. The identified benefits will be first presented graphically and then will be analyzed, as explained earlier in chapter 3.3. The top identified benefits are shown in the next figure:

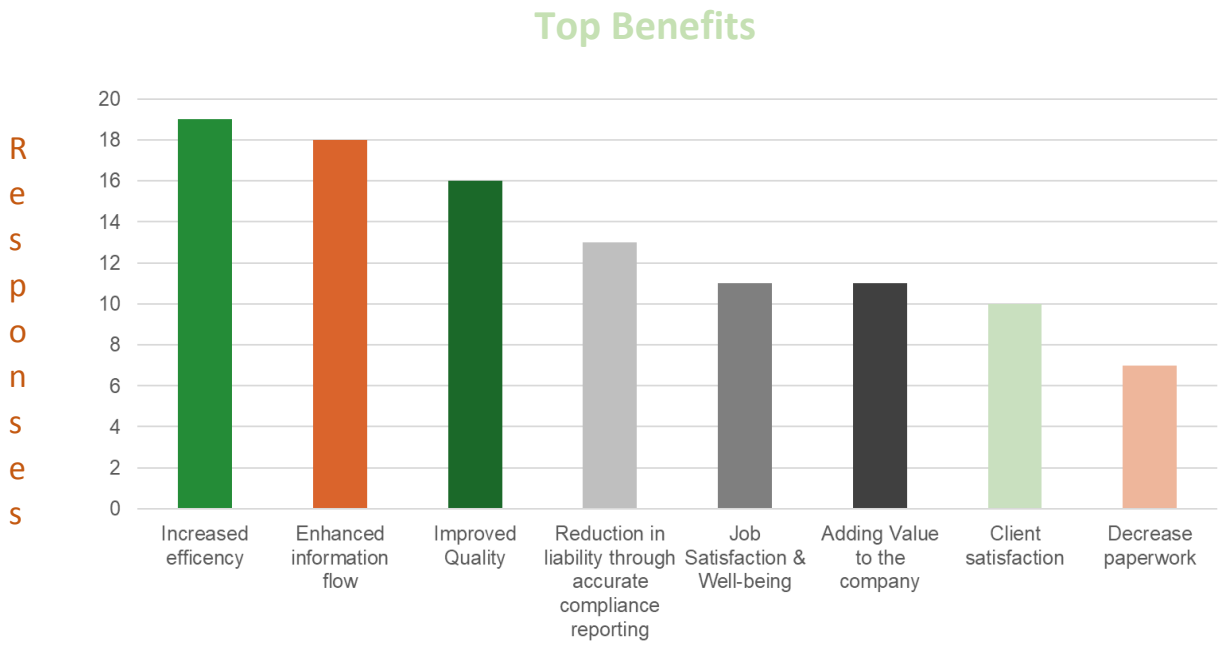



*Figure 10-Top Benefits*

As shown before (figure 6) the interviews were conducted with site engineers, planners, project managers and digital construction managers. For this reason, apart from the graphical presentation of the top identified benefits from all the respondents, a spider-diagram will be created to depict the variance regarding the different roles of the interviewees. The spider diagram is presented below:

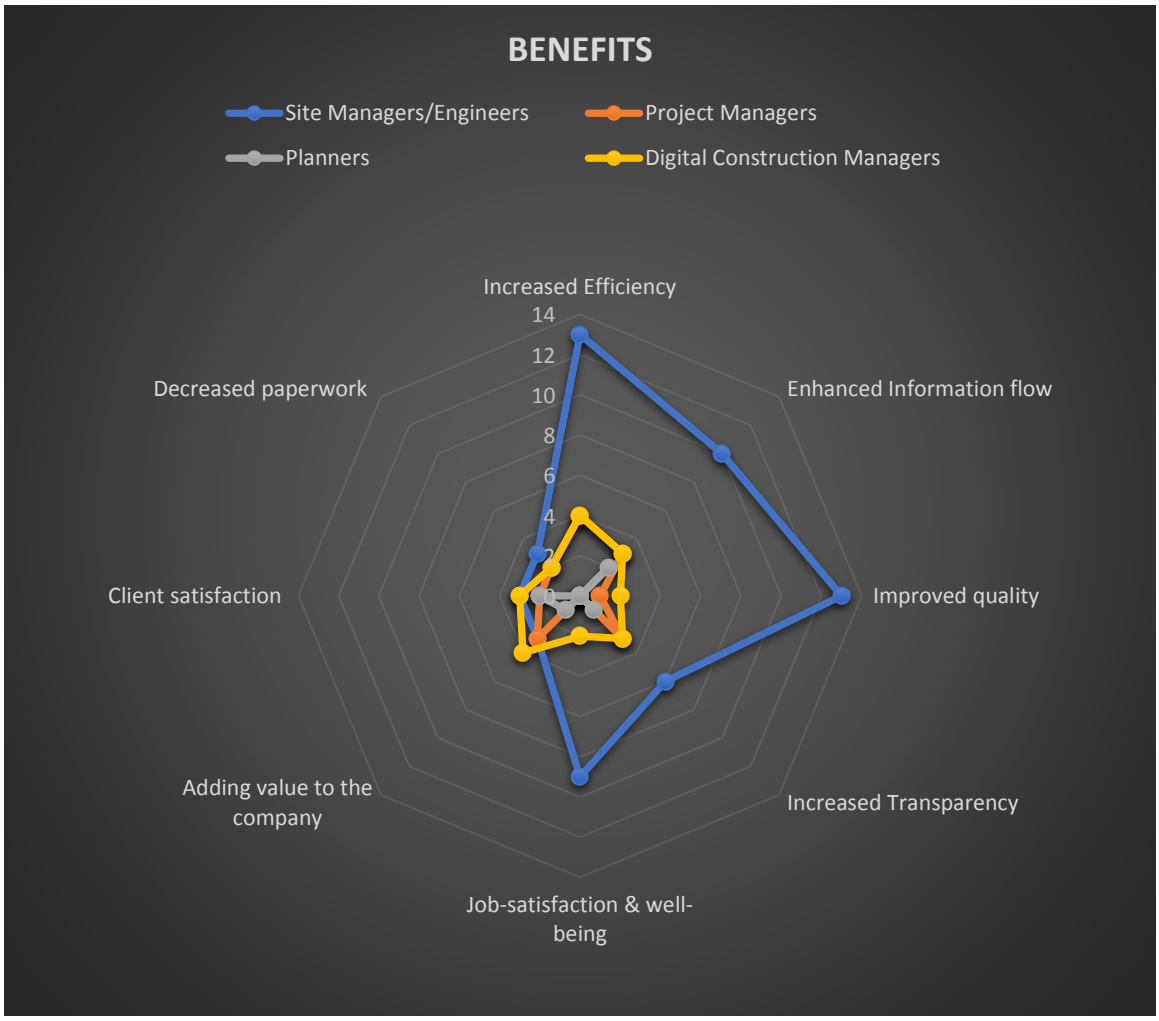



*Figure 11- Distribution of responses (benefits)*

As can be seen from the spider-diagram above, the site engineers were mainly identifying benefits that were directly related to their personal tasks, such as efficiency and improved quality of information. Whereas, the majority of the project and digital construction managers acknowledged the beneficial impact to the organization, be often referring to added value to the business and client satisfaction.

Next, the top identified benefits will be elaborated and analyzed:

**Increased efficiency**

The project manager of London City Airport stated that in construction we are very good at making simple things complicated and putting more and more people into the non-value added activities. For example, thinking about an engineer on-site he has to capture all his data in his level book, come back into the office, type all that information into a computer and then share this data by sending multiple emails. There are too many people who are highly educated, spending a lot of time filling in data on Excel spreadsheets and wasting their time. Where digital transition comes in, is that it can save significant time, allowing people to actually think more about their role and how they can increase the profit margins and add value to the business. According to the interviewees, the biggest expenditure of the company is people, the company spends more money on people than anything else. For example, saving one hour from an excavator that is idle for this hour, is not as much of a physical cost for the company, compared to having a person doing a non-value added activity for this hour. The use of these tools allows the site engineers to stay out on site, without having to come back to the office to resolve an issue. They can spend more time doing things from the quality side, rather than doing paperwork or the risk of not doing anything while they are on the field. An indicative example of how mobile tools can increase people's efficiency was provided by the project manager of the Little Queens project. According to the Little Queen project manager, "main benefit for me is the increase in efficiency, as one example is a permit to dig. Traditionally, what normally happens on a site was for the foreman to ring up the engineer informing him that he needs the specific permit. Then the engineer should type out the permit, take it to the foreman out on site to sign it and then the engineer should bring it back to the office, once the task is completed, scan it, upload it in the system and send it if necessary to certain people. Whereas now, the foreman digitally informs the site engineer that he needs the permit, the engineer uploads it on the system and everybody can sign it automatically on their tablets. This process takes a matter of minutes to complete, whereas in the past was taking more than an hour".

**Enhanced accuracy and flow of information**

The construction project is a fast-moving process. Having real-time digital information, enables for better decision making, better judgement in less time; avoiding in that sense potential mistakes and reworks. Traditionally, the information flow upstream with the client and downstream with the workforce and the subcontractors, is languid. For example, raising an RFI for a technical issue on a drawing, might take up to a month to get a response, preventing an immediate and correct resolution of this issue. The site engineers pointed out the fact that when they have up-to date information, an updated drawing, they can be more confident to make a decision, without the need of checking whether is the correct drawing. With the use of mobile tools, the drawings are revised almost daily, thus every time a site engineer opens up a drawing on his tablet it is ensured that it is the latest revision. In many cases in the past with paper drawings, a lot of mistakes happened because they were old revisions on the field.

**Quality Increase**

Using mobile tools to digitally capture field data has a great impact on the quality of the end product-project, as derived from the interviews. Having the all the required information, for example the drawings or 3D models in the tablet, it means that the site engineer can inspect the works while he is outside on the field. Traditionally, the site engineer should go back to the office in order to get these kind of information. The use of the mobile device has given the opportunity to switch between different drawings, specifications in order to ensure the quality. Moreover, by digitalizing the quality inspections through the use of mobile digital tools, they are becoming more standardized and easier accessible, increasing the possibility that a defect or an issue will not be overlooked during an inspection. The issues are captured and stored digitally, creating a clear audit trail making more difficult for them going ignored and unresolved. According to the design manager of BAM Construct, "the biggest challenge for the company is to reduce and eliminate defects, that are a threat to the business reputation and profit. By improving and making easier the automated field data collection through the use of these mobile tools, we improve the chance that people will identify issues and resolve them faster".

**Reduction in liability through accurate compliance reporting**

According to the interviewees the digital capturing and sharing is making the information a lot more transparent among the team members, the subcontractors but also with the client. Having all the information in BIM or digitally, there is only one version of truth. Traditionally, in every construction project there are a lot of disputes and potential claims regarding costly errors or delays that took place. Using mobile digital tools for reporting information digitally and real-time, is putting the business in a much stronger position to be able to recover the client change orders but also for errors that the company is not liable for, for example mistakes caused by the subcontractors. As being stated by the senior planner of the London City Airport project, "there are hundreds of change orders from the client. Maybe an area is not accessible for the time you need to work in it or you need more resources. 95% of the planners in the UK do not take into account these changes and will they will be executed by the workforce without updating and submitting to the client the new schedule. What you should do, is keep track of the compensation events that are taking place in order to be able to claim money. If your team does not have a site tool to update the schedule real-time, all the valuable information will never be captured. The problem is in these compensation events is that the project team and the client are not aware of these changes".

**Job satisfaction & Well-being**

A really influential and vital for the company benefit that derived from the interviews was that the use of digital mobile site application does have an impact on the user's job satisfaction and well-being. Having the information real-time and all stored in a common platform, CDE, the site engineers acknowledged that is making their job significantly less stressful. According to the site engineer of Oldbury project, "these tools are very convenient for us and make our jobs far much easier. Also, by having a common platform to share the information, decreases the number of potential disputes among the team members. Sometimes is annoying when someone is working on separate ways, keeping all the files into his personal drive". Something that is easier to do outside on the field, obviously reduces stress levels. The users of these tools, mainly the site engineers, get frustrated with having on to duplicate captured information, spending much of their time searching and carrying with them a huge pile of paperwork while they are on the field. It also has a great effect on the well-being of the recipients of the information. As was stated by the quality manager of Oldbury project, having the information captured and shared digitally is making his work less stressful. "When I got a huge pile of paperwork on my desk, and had to stand in front of the printer for 2 hours making everything digital it is really stressful for me. During that time, I could do something better, a value adding task". Moreover, from the perspective of the recipients, they agreed that when you capture data digitally you can have a better record-keeping without getting frustrated searching for papers, asking different people to pull an important information. Digitalizing the information, the recipients can look up themselves and automatically pull that information, at any given time.

**Adding Value to the company**

Capturing information digitally, increases the chance of a successful performance monitoring comparing to the traditional method. The digital data can be easily extracted and stored in a structured manner allowing the project managers and the organization itself, to keep an accurate track of the project's progress, the performance of the project team and subcontractors, the issues that appeared during the construction, the root-causes of these issues and many more. The information can be transmitted directly from the field to the organization. Giving the chance to the company to compare the performance of a project against the predefined performance indicators (PI's), against other similar projects, identify the most prevalent and usual issues and be able to make better decisions. According to the digital construction manager of BAM, "one of the main benefits of capturing digital data, is the ability to create dashboards from the data that is being recorded and analyzed. And that is the bigger picture that we, as a company, definitely need. By capturing data in paper, it is impossible to extract all the necessary field information and report it to the company. If it is digital, I just can go back to the history of a project and found the information. In that sense, I may offer some extra value to my current project".

**Client Satisfaction**

This new digital process of capturing field data has significant advantage over the traditional methods of handover and facilities management. The data is automatically stored in a single and accurate documentation database in which as-built data is stored and which can be visualized clearly. According to the interviewees, the client wants a digital data handover and if the company cannot deliver that, the chances of working again with that client are significantly weakened. If you are obliged to deliver digital information, then it is necessary to use site digital tools. The great benefit of the digital information comparing to the paper method, lies to the fact that the data is stored and secured. For example, in case a system needs to be maintained after some period of time, the digital information is readily available containing all the necessary specifications and drawings that are needed for the repair. The possibility of missing handover information is extremely high when the information is stored in paper. Apart from the benefit of improving the handover information, the digital capturing and sharing of information, is giving the client a perception that his project is well managed and can also track and monitor the progress instantly. In essence, the client can review the data instantaneously, as the information comes through, ensuring that the project can be delivered on time or even ahead of time, promoting the company, as a company that can deliver. The quality manager of the Thames Tideway project shared with the author, his experience in a previous project that the data was captured manually in paper form. “On my previous project there was the misconception to the client that assurance was not being secured due to lack of visibility and we had to go through a very onerous verification process at the end of the project, that took much longer than should have and essentially delayed the overall completion of the project. Therefore, by using these digital tools, is making easier to capture the information in the first place, then making it easier for people, whether it is myself, as a quality manager or client as recipients to this information, that they have the right information. After the end of the construction phase, you then have the delivery, the assurance, the operation and the maintenance of that and if these records are not being captured digitally during the construction, it makes these follow-up stages awfully difficult. Going back to my previous project, the delivery of the project was 18 months after schedule, due to all the unclosed issues, that needed to be validated and submitted to the client”.

**Decreased paperwork**

When you capture data digitally, the need of printing and carrying around a huge pile of paperwork is substantially decreased. Apart from the generation of unnecessary extra costs for printing and shipping paper, there is also an effect in terms of the storage. According to the project manager of Streatham project, they currently save all their paperwork in the site office and in a short period of time, they will not have enough space for further storage of paper. Apart from this example, having vast amounts of paper either on site or in the site offices, automatically creates a negative image to the organization top management level, such as directors, as well as to the client.

## 5.2 Identified implementation barriers

The present sub-chapter is addressing the 3nd research question. During the interview process, eight main barriers emerged within the projects that are hindering the adoption of mobile digital site management tools. Similarly, with the benefits, the barriers are depicted in the following graph and then analyzed and discussed.

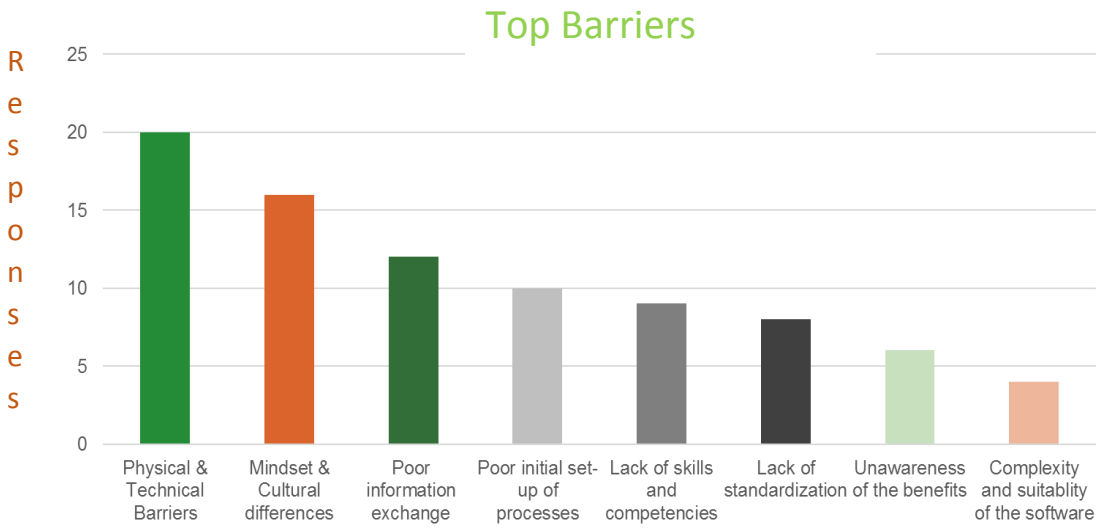



*Figure 12-Top Barriers*

Similarly with the sub-chapter 5.1, the following figure depicts the variance of responses regarding the identified barriers:

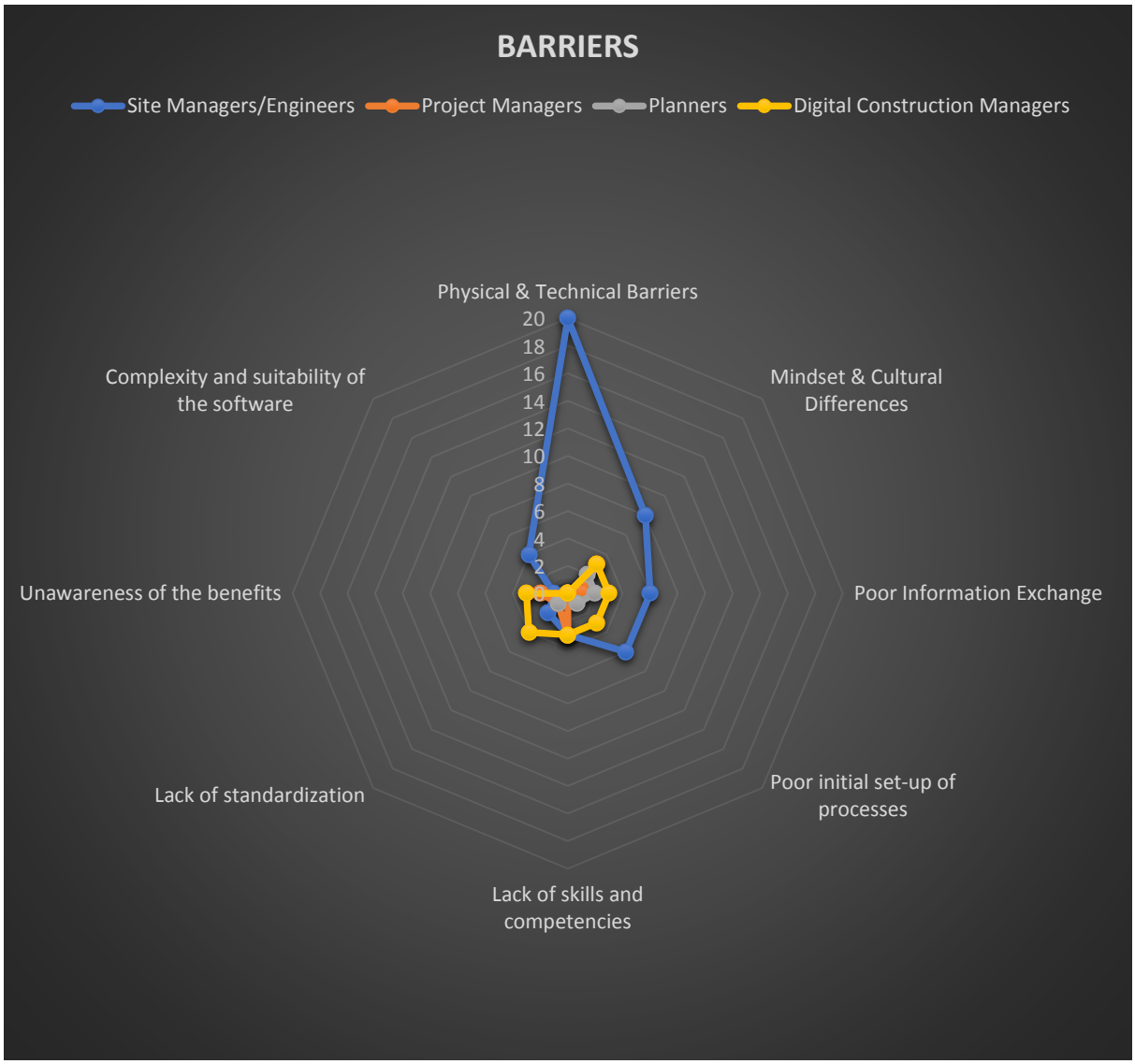



*Figure 13- Distribution of responses (Barriers)*

The top barrier (physical & technical barriers) derived solely from the site engineers perspective, as they were the only ones pointed this problem. Interestingly, the second main blocker, 'mindset differences', has not be highly acknowledged from the site engineers. The digital construction managers mainly acknowledged the lack of standardization and mindset differences as the most important blockers.

**Physical & Technical Barriers**

A more specific challenge that arose under the implementation of mobile devices was the hardware itself and network connectivity. During the project, the site engineers are really active, often have to climb up ladders or reach difficult places. Also, they often carry additional tools, for example to measure. Hence, carrying a delicate and sizable i-Pad is proven to be quite a challenge, as they should be extra careful not to damage them. On a construction site, there is also a lot of dust and moisture, so the hardware used must be resistant enough to withstand such a tough and challenging environment. The users, also, stated that sometimes the quality of the mobile device is not adequate enough. The devices did not have the right capacity to handle the modern software, as a result the device was either crashing when opening the model in the app or either it was taking a long time to respond. Another physical barrier derived from the interviews, was the limited battery capacity of the device. The site engineers often return to the office during the day only to charge the battery, wasting time and getting frustrated. According to the site engineer of London City Airport, "You do not want your mobile device to be slower than your computer because I may as well use my computer. It really depends on the quality, that needs to be decent". The construction site also needs to have a good and stable internet connection to the get the full benefits of the mobile devices. Almost none of the projects did offer a network connectivity on the site, urging the users to use either 3G or 4G connection using their personal SIM card. The site engineers should return in the office in order to get an internet connection to sync their i-Pad and update them with the latest drawings and information. In some projects, the mobile devices handed to the site engineers did not even support 3G or 4G and could only have internet access through Wi-Fi connection. The value of the mobile device gets significantly restricted without an internet access, and that drove the users to go back to the traditional paper workflow to execute their tasks.

**Mindset & Cultural aspect**

Through the interviews it became clear that there is a cultural and often generational gap when it comes to the use of new technologies and digital site management workflows. In general people are resistant to change. When introducing mobile digital devices and new processes, the cultural aspect and users' reluctance should be taken into account. These new approaches were regarded sometimes by older generations as unnecessary and thus they refuse to adopt them. The main reason behind this is that the older site managers and foremen lack the knowledge and education in new technologies, since they were not raised in a tech-environment compared to the younger generations. Site managers, with 20-30 years of experience, are used to work in a certain way, and a change in their current working practices is maybe the most insurmountable barrier. However, during the case-study was identified that the mindset of people does not necessarily depend solely on the age. There were some cases that the older generation were very eager to familiarize themselves and learn the new processes, due to the fact that they were tired of following the traditional processes and acknowledged the inefficiencies of those processes. Certain individuals will always be looking at problem-solving and making their job more efficient, identify themselves a replication of work and strive to discover a better way to actually deliver their tasks in a leaner and efficient manner. What is worth mentioned regarding the generational

gap barrier, is that the young engineers tend to give the software packages higher importance and forget the civil engineering content. According to the project managers, the young engineers should go through a maturing process on the site without skipping steps by using the field software as this will have a detrimental effect to the engineering way of thinking.

**Poor information exchange**

The information exchange has proved to be a significant blocker according to the interviewees. Typically, in a construction project the site data should be fed to plenty of interested parties, such as the client, the project team and the subcontractors. Each of this parties have different requirements regarding the format that they wish to receive that information, different software, filing systems and templates. More specifically, the site engineers are using a certain software tool to extract information with their mobile device. This information will automatically feed in and used by certain people in the office, mainly the project team. After the information has been extracted and stored in this system, the site engineer should come back in the office and manually translate and feed the same information to the other systems used in the project. The same struggle appears to the recipients of the site information, that they still have to translate the information to feed their own systems. Currently in the BAM's projects, when the information is digitally captured in the field using a specific site software application, it has to be transcribed in different formats and fed to different systems by the site engineers in order to update all of the recipients. Hence, the information that has been already extracted, is duplicated in other systems, causing severe frustration and time-waste. The main reasons for this phenomenon, is the lack of interoperability among the different software tools and the lack of a consensus among the parties in the beginning of the project to use a particular software. Unless, the information is not automatically feeding other areas that the project needs to comply with, for example the client requirements, the digital site data capture will not add value and be adopted to its' full potential.

**Poor initial set-up of processes**

An important blocker, is that the digital processes are not well-established before the start of the construction phase. Hence, the project team is starting to collect site data with the traditional paper method, since it is the only possible way. The project team is struggling to develop the digital processes (forms, templates and method of capture), as a result they are trying to catch up during the construction phase and turn the paper notes or long spreadsheets into valuable and digital data.

**Lack of skills and competencies**

The lack of skills and competencies of the project team can be perceived one of the main barriers to the adoption of the digital tools. To fully leverage and acquire the benefits of digitization, a certain amount of knowledge and skills are required regarding the application of specific software tools. The site engineers and other users of mobile digital technology, are relying quite often to

the digital experts to help them in order to complete their tasks. Hence, the misconception that the digital method of capturing data is not as effective as the traditional method is generated. People think that the new technology cannot really offer what they need and decide to turn back to their old processes, since they do not have the knowledge of using it. This phenomenon has appeared in several occasions in the projects, however the people responsible for the site activities, site engineers, do not really perceive it as a barrier. The above conclusion was drawn from the conversations with the project management level, especially the BIM managers. According to the BIM manager of London City Airport, "one of the main reasons we have not adopt the use of digital technology on site, is because we do not have the right people, the right resources, people with the right skills and knowledge to be able to use the digital tools effectively in the office and on-site".

**Lack of standardization**

The digital transition is currently an on-going process for the organization of BAM. In the majority of the projects of this multiple case study, people on site were using mobile devices to capture and share field data. However, it has been noticed the absence of a single and unified approach. This approach consists of 3 main aspects that can be represented by 3 of the H5W. More specifically, the selection of the software tool for collecting field raw data (how?), the kind of data that needs to be collected and shared (what?), and also which part of this data should be reported to the organization(why?). There is a lack of consistency regarding the capture, processing, reporting and presenting the project field data, that caused a lot of confusion and frustration among the site project team. According to the site engineer of Oldbury, "In my previous project we were using Aconex for capturing raw data, whereas in this project we should use BIMfield360. It has become really frustrating almost every time, I switch to a different project I have to be trained from the start to learn a new software tool that I know I might only use it for the ongoing project. The lack of a standard process is surely one of the reasons that I choose to execute a lot of my tasks on paper and not digitally". Furthermore, regarding the initial set-up of the processes, it is highly linked with the absence of a standardized approach. In almost all projects, the digital process for site data capture was not developed in the beginning of the project. Meaning that the tool did not include the necessary digital templates and basis, in order for people to use it on the outset of the construction. Also, the BIM model was not directly linked with the templates and drawings, since in many occasions there was not a fully developed BIM model from the designers when setting up the field software tool. That has urged the use of paper method to capture the data, since it was the only option and people carried on until the end, as it would take a huge amount of effort to turn the paper-captured data into digital data, by the point the digital process was ready to be used.

**Unawareness of the benefits**

An important barrier for the people to use the mobile site applications, as well as for the organization to invest on them, is the lack of proof regarding the benefits. According to the interviewees, there is no reason and motivation for switching the current processes of implementing a certain task, unless there is a solid proof that the new process can offer benefits. In terms of the users, they are willing to adopt the new technology in case they are convinced that offers value to them, decreasing the effort that is required to execute their tasks and also that can have an impact on their personal development. From the organization's point of view, the lack of tangible benefits is the main reason that prevents the full adoption of the digital processes. The lack of proof that the digital site tools can increase the productivity of people on site and also increase the projects' profit margin.

**Complexity and suitability of the software**

The software itself is playing an important role that can hinder the adoption of digital site management. According to the interviewees, the software must be user-friendly and easy to leverage. Moreover, it should fit the needs and requirements of the user. Currently, the software does not support all the site engineer tasks, driving them to use the traditional method to complete those tasks that are not supported. When asked for the reasons that mobile devices have not been adopted by the engineers in the London City Airport, the project manager stated "the reason why people were reluctant to use them was that the system did not fit the engineers' requirements. We tried to get something set up digitally and maybe it didn't work or didn't work for them. There was always a question came out "can it do this? Can it do that?" "Actually no". And as soon as you start getting the negative answers, then people say it is no good and they will carry on doing the way that are used to". The software adopted by BAM's projects was not flexible and changeable enough to meet every project's requirements and it is a matter of the software developers to enhance their software's capabilities but also a strong organization as BAM to drive and guide these changes. However, the software industry is continuously developing and it is not a question if it will become suitable, but rather when it will be become. Nevertheless, it is something that the company should take into consideration before investing, in order to persuade more people to adopt it.

## 5.3 Solutions

The present sub-chapter is addressing the 4th research question. During the interview process, 17 main solutions emerged within the projects that could boost the adoption of mobile digital site management tools. Similarly, with the benefits and barriers, the solutions are depicted in the following graph and then analyzed and discussed.


*Figure 14- Top solutions*

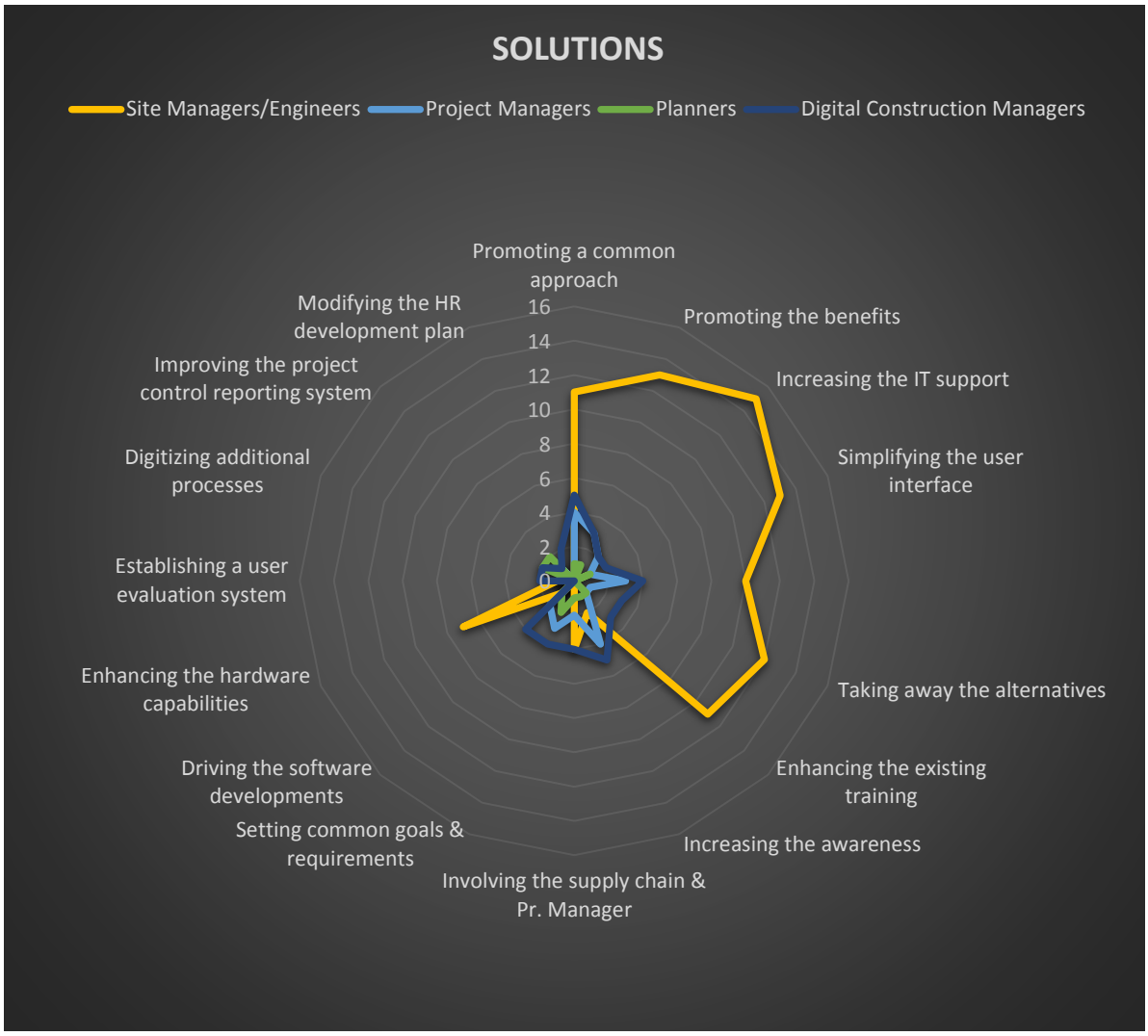



*Figure 15- Distribution of responses (solutions)*

As it can be seen from the figure above, the solution with the most responses, 'promoting a common approach', was an outcome of all the different roles of the interviews, whereas the increasing IT support and taking away the alternatives mainly derived from the site engineers point of view. Another interesting fact of this spider-diagram, is that the suggested initiative to enhance the hardware capabilities was only stated by site engineers, which is in line with the top identified barrier "physical & technical barriers'.

Deriving from the thematic analysis, the collected data seems to follow 3 different patterns. Thus, all the potential solutions will be categorized into these 3 patterns, which can be named as the 3 key drivers for boosting the implementation of digital site data tools, given the purpose and nature of their content. The 3 key drivers are:

- ***People***
- ***Technology***
- ***Process***

Furthermore, apart from this categorization (3 key main drivers) that derived from the thematic analysis, the author will characterize each one of the proposed solutions according to which stage should be put into practice by the company. These construction stages are:

1. **Preliminary Stage:**

The first stage refers to the situation before the start of the tender or design of a project. It relates to the general situation and approach of the projects from the organizational perspective.

2. **Pre-Construction Stage:**

This stage entails the initial set-up the project. More specific, the tendering, the planning and the design of an upcoming project.

3. **Construction Stage:**

The construction stage is strictly focusing on what happens on-site during the construction activities. The actual implementation of the mobile tools is taking place on this stage, however not all the problems and solutions are linked to this stage.

4. **Post-Construction Stage:**

The final stage is the post-construction stage. After the completeness of the construction and final handover to the client, there are certain actions that can be taken from the project team in order to increase the adoption of these digital tools.

### 5.3.1 People

*Table 4 -Solutions (People)*

| People | | |
|---|---|---|
| **Solutions and potential initiatives from the company** | **Adressed barriers** | **Stage** |
| Enhancing the training scheme | Lack of skills & competencies<br>Unawareness of the benefits | Preliminary & Pre-Construction |
| Modifying the HR development plan | Unawareness of the benefits | Preliminary |
| Increasing the awareness | Unawareness of the benefits<br>Cultural aspect & Mindset | Pre-Construction |
| Establishing a user-evaluation system | Lack of skills & competencies | Preliminary stage |
| Promoting the benefits | Cultural aspect & Mindset<br>Unawareness of the benefits | Construction |
| Taking away the alternatives | Lack of skills & competencies | Preliminary |
| Involving the supply-chain & pr.Manager | Unawareness of the benefits | Pre-Construction |

According to the design manager of BAM Construct, the key driver for adopting the digital site construction tools is the people. The people make it happen and without their trust and support on the digital process, the implementation will never be fully adopted. When it comes to people, there are certain initiatives and actions that BAM, as an organization, can take in order to swift the mindset of people and take them on board.

**Enhancement of the existing training scheme**

For the successful implementation and utilization of digital tools and processes, specific knowledge and skills are required by the personnel. Thus, the organization has certain choices to overcome this barrier. The company has the option of hiring new resources, mainly site engineers or site managers, that already have a digital background and education. This solution however, might not be the most effective one, as it is an extra avoidable cost to the firm and also the new personnel may lack on engineering knowledge and experience comparing to the existing one. Better solution to this problem can be the enhancement of the *existing training scheme*. The current BAM training scheme for the site personnel usually involves a one-day or half-day training

course of a group a people in a room. This training is delivered by a digital construction expert and focuses on a superficial understanding of the new software used on the project. This approach has not been proven efficient as the users do not really implement the training on real-project situations and they often keep going on with the old processes, as they tend to forget what was in the training. Hence, the training should become more practical and based on real-life scenarios and situations. There are different paths that can be followed regarding the training. The first choice is adopting a longer training course in the beginning of the project. Increasing the duration of the training, can give the opportunity to the facilitator, probably a digital construction manager with high experience and teaching skills, to create a mock-up of the project. By creating different imaginary scenarios that the users could face on the project, the facilitator could explain and present how the use of the digital construction and process can be used in a more efficient manner. What is also important for the success of the training is the direct involvement of all the roles of the project. The facilitator of the project has the knowledge how to connect a certain task with the software and digitally implement it. However, he may not be totally aware of everybody role and responsibilities on a project and what has to be achieved from an engineering perspective. Therefore, the training must acquire a more interactive approach, giving the chance to the users to explain what the tasks are, in order for the facilitator to better plan and explain the digital process and how the digital tools can be used for every purpose. Moreover, according to the interviewees it is important to make this training more "attractive" to the attendants. Motivating people to attend and increase their willingness to be vividly involved in it, by offering for example free lunch and also the chance to get the rest of the day off after the training. There are some limitations of the aforementioned type of training scheme. Construction projects have a dynamic nature, meaning that project requirements might change and the personnel might move to another project. Moreover, finding the available time to actually dedicate for this one-week or 2-week training might prove an insurmountable task for a construction project. According to the digital construction manager of BAM Construct, "the most suitable training scheme is the module training. The training must be spread over time and when we need something, rather than training someone with all the skills and techniques that are not required for the project and eventually forgetting about those training techniques". To increase the impact and success of the module based training, it would be important to take place on a specific setting. The training should be adjusted accordingly to whoever needs to be trained. For example, the site engineers and site managers are used to work outside on the field, therefore the training should be interactive out on site. Whereas, office personnel such as planners or quality managers should be trained indoors. Ideally, a small group of site engineers would be taught by an experienced person, either a site engineer or digital champion, to physically learn the capabilities and how to use the system, while they are on site. As the project manager of T-Zone stated, "the only way to make a person use his i-Pad is if he uses it. Some people, especially in our industry, are more practical and learn things quicker by actually doing it as opposed to sitting around of a table looking at the screen. Also, it has to be a continuous process all the way through the project". The module-based training could also be supported by online video tutorials or PDF guidelines for every of these newly introduced digital processes, that are easily accessible to the user. The enhancement of the training scheme is an action that should be taken in the *preliminary phase*, prior to the commence of a construction project.

**Modifying the human resource development plan**

In order to establish how the new capability is built up among the users, there is a need to *create/modify the human resource development plan*. This plan should start with an analysis of the current skills of the employees inside the organization and the potential which can be developed with trainings. Within BAM, there is already a development plan analyzing the competencies of an employee regarding the digital capture of information, called "6D Handover competencies". What can be proposed is that the training should more connected to the development plan, in order for people to be able to see the outcome of the training being reflected on the development plan. Also, giving extra motives to people acquiring the related skills, such as increased chance of promotion, salary increase etc...Hence, the employees could identify certain benefits that this digital transition can offer to them as well. The modification of the human resource development plan should also be put into effect during the preliminary stages.

**Establishing a user evaluation system**

Moreover, *establishing a user evaluation system* from the company, by monitoring the number of reports, quality inspection and other reports made by the user, might be able to encourage the users to using them. With the paper-based method, the identification and monitoring of the data capturing and reporting by the user is almost possible. Having an evaluation system as an obligation in the projects, people would have no other choice rather than using their tablets to capture data in order to prove their solid performance. For this reason, people would be more eager to enhance their skills and knowledge in order to be capable of leveraging these tools and new process. The establishment of a user evaluation system is again an action taken in the *preliminary* stage.

**Promoting the benefits**

Although it is important to know how to use a new digital tool, there is not a direct link between knowing how to use it and seeing the benefit of using it. Therefore, it is vital for the digital department of the company to *promote the benefits* that derive from these digital processes to all the different roles, from the site engineer, the commercial department of the project until the top management level of the company. People, especially the older generation that they used to a traditional way, need to see the benefits in order to change their mindset. Shining to them the benefits in a friendly way as well as spending time with them to explain how these new tools can make their jobs easier and better for them. According to the site engineers, "if somebody demonstrated to me that is going to make my life easier, then I am all for it". To get people to see the benefits of implementing a new tool like digital mobile devices, it is important to promote success stories and increase the communication among co-workers with the same role. For example, a foreman who is reluctant to adopt new technology, will not be persuaded by seeing the benefits that the new tool brought to a designer or site engineer. Hence, getting him to talk with another foreman who successfully adopted the new technology to execute his tasks is probably the most impactful approach. Counting on people's nature, they want to be the best or try to be the best, thus promoting one project or individuals that implement a tool that makes them more efficient, it is expected that other people would want to try out this tool. From the

organization perspective, investment on the new digital mobile technology, can be granted by providing a positive return-on-investment (ROI). For that, it is important to run a pilot-project that gets extra attention and monitoring to secure a success or as in the case of this dissertation, a case-study approach. The action "prove the value" is an action taking place during the *construction stage*.

**Taking away the alternatives**

An additional and rather drastic decision that the company could take is *imposing* the use of digital mobile tools or *taking away the alternatives*. This particular solution is probably the most controversial but it was also the most prevalent answer among all the interviewees. There are cases that presenting and explaining the benefits might not be enough to change the mindset of individuals, therefore other options should be considered in order to persuade people to learn the new digital method. As a company, mandating these tools and restricting at the same time the alternatives can be proven to be a huge boost in the adoption of digital tools. According to the digital construction manager of London City Airport, "if we force it on people, they will learn very quickly because they have to. You are going to have mixed results, and some people would may want to quit their jobs. Is that a bad thing? Because whoever comes in to replace them, might have a better attitude. It is harsh. I have been trying to train and change hearts and minds for over 10 years. Some people just do not change, hindering progress. Because if other people seeing them not changing and getting away with it, then will not be encouraged to change as well". An indirect way of imposing the adoption of digital tools and stray away from the traditional paper method is taking away the alternatives for people. For example, not having a printer on the project office or providing a single digital approach to capture data, people will not have another choice than using them. However, prior to enforcing it, the company should make sure that the project has access to the mobile devices and to a solid digital platform. Taking away the alternatives can be done in the preliminary stage, since it must be decided from the top management level of the company.

**Increasing the awareness**

*Increasing the awareness* about the value and necessity of using site digital tools may also be an important aspect. Apart from seeing the personal benefits, people can also be encouraged by realizing more organizational benefits, that could potentially derive from the importance and necessity of the digital information. When it comes to the users, it is important to understand why they have to measure and collect data, and to what extent this data is important for the success of the project but also for the development of the organization. According to the quality manager of Thames Tideway, "quite often people do not know why we need an ITP; showing them how important is this information, it would encourage them to use these new digital systems. Similarly, increasing the awareness of the senior management of the organization, such as directors. It is important for directors to realize the value of digital reporting and real-time monitoring for keeping track of the projects performance but also for keeping history records to minimize defects and mistakes of the past. It comes down to the digital department of the company or the project managers to try to increase the awareness of the directors and manage to take them on board. Increasing the awareness should be put into effect mainly during the *preconstruction stage*.

**Involving the supply-chain & Project manager**

One of the basic steps towards a digital implementation in any project, is having an *appropriate project manager*. The project manager should have some additional qualities, such as a technology background, ability and motivation to be trained in new and different software. This manager should be familiarized with the digital software used by the company, without having to be an advanced user. He should understand its purpose and be able to competently explain the software to other users and speak about the processes when reporting the implementation status. To that direction, project managers should be involved early in the project, in the projects' kick-off meetings and try to familiarize themselves with the new processes. According to the interviewees, there is no point of sending trainers for the teams, unless the project manager is not only supporting but also driving the digital transition as well. The project manager can provide the necessary authority to state what is needed in the project and how should be implemented. Appointing a *digital construction manager/ BIM champion* to support the construction site, can offer a huge boost and confidence to the users. In line with the module and continuous training discussed above, the BIM champion can solve all the inquiries that the users might have over the new tools as well as giving an extra motivation to them. Lastly, an important aspect that could urge and increase the adoption of mobile/cloud based technology is the *involvement of the supply chain*. The mobile technology is there for many reasons, not only for the site managers or site engineers, but it can be proven beneficial for a design manager, a planner, a safety manager and subcontractors among others. Particularly for the subcontractors, making them buying into the digital world is not an easy task. Getting them on board will require a combination of all the drivers mentioned before (people, technology, processes). The solutions regarding technology and processes will be discussed later on this chapter. Regarding the "people" driver, getting them on board, is something that should be decided early in the project, during the tender stage. Before the contracts have been signed with the subcontractors, the company should be legally ascertained that they have already bought into the digital process. And more importantly, when they are on site in the beginning of the project, an absolute demand must be issued that they have carry on with that process. Complimentary to that, the subcontractors should be equally trained along with the project team members. Again the module training based on-site is probably the most effective solution, as the subcontractors are also used to be on-site and have a more practical nature. The involvement of the supply chain and project manager has to be done during the *pre-construction stage* of the project.

### 5.3.2 Technology

*Table 5-Technology Solutions*

| Technology | | |
|---|---|---|
| **Solutions and potential initiatives from the company** | **Adressed barriers** | **Stage** |
| Simplifying the user-interface | Complexity & Suitability of the software | Preliminary & Pre-Construction |
| Driving the software future developments | Poor Information Exchange | Preliminary |
| | Complexity & Suitability of the software | |
| Increasing IT support | Complexity & Suitability of the software | Construction |
| | Physical & Technical Barriers | |
| Enhancing the hardware capabilities | Physical & Technical Barriers | Preliminary & Pre-Construction |

The next key driver that will be elaborated below is the technology. There are several potential solutions in terms of technology that could vividly boost the adoption of mobile site management applications.

**Simplifying the user-interface**

The first aspect that the company should look into in terms of the *software*, is providing to the users a *simple software* interface. Making the interface user friendly and easy to use will drive people to start using it. There is no point of having a software application that is really complex and only a certain amount people can use. The application should be easy and straightforward like the mobile applications that everyone has on their phone, without the need of extensive training. According to the quality manager of BAM Construct, “If the technology is easy for people they will use it. What generally is demotivating for people, is when things are clunky, complicated, that is when people do not use things. If you can make it like a simple interface, which is very intuitive that everyone can pick up and does not even necessarily need to know a lot about technology, but just can take his tablet and just work his way through a series of visual images or

icons to take him through the process in a very intuitive way, he will use it. If you think about the best apps and games, are the ones that people can just pick up and use straight away, without having to read instruction manual". Hence, the company should also look at the complexity of the software applications before deciding to purchase them, and provide to the projects simple but also effective ones. Simplifying the mobile software should be decided in *preliminary stage or pre-construction stage.*

**Driving the software future developments**

Furthermore, what can be proven a "game-changer" in terms of the software improvements, is making the software applications *accessible to all mobile phones*. According to the interviewees, having the software applications on their phone would help overcome a lot of technical barriers regarding the use of the digital tools and will reduce the risk of losing or damaging a tablet. Especially for engaging the subcontractors to the company's digital process. As the digital construction manager stated, "if we want the supply chain to come on board with technology, the only way to that is with mobile phones. Tablets cannot be issued to all the subcontractors, but everyone tends to have a smart mobile phone these days. That can make the subcontractors start working within our processes". Although there are software applications that are currently accessible via mobile phones within BAM, however they are only supported by IOS system. Not everybody can afford to have an I-phone, therefore the applications should also be supported by android and other systems. Moreover, a common problem faced by the users in BAM projects, was the synchronization of their mobile devices in order to have the latest updated information. For the users, was an extra thing to remember at the end of the day and in many cases were forgetting to do it. Having a *systematic and automatic synchronization* of the software, could take away an extra responsibility of the users and also ensure the accuracy of information in the system. Another thing that the company but also the software vendors should take into account, is *dealing with interoperability issues* among site digital applications. In all project sites, there are various external people that require the captured information. However, the majority of them have their own platforms or CDE's to view the information. Different software should overcome the interoperability issues, that are causing poor information exchange and communicate with each other, in order for the information to be automatically reported to all the interested parties. The use of open standard files with a centralized database server to encourage openness is definitely essential to the wider adoption. The solution to this must derive from the software vendors, but a simple solution is providing the automatic export function to Excel files and from that point can be imported to the different software. Also, the software vendors could collaborate together, in order for their tools to support the same API specifications. Moreover, the prospect of *integrating the digital information with the location tracking technology* for construction field management, could have a major boost to the efficiency and adoption of mobile tools. The paper or tablet-based walk through monitoring and data collection without locational information attached to the data would require extra efforts to link the data into the monitored components. The effectiveness of such a tool could be proven beneficial in both environments, 2D and 3D, as the user could open the model or the 2D drawing from his tablet and save valuable time. A tangible way for integrating the digital information (drawings, model, specifications0 with the location tracking technology, is by creating a field mobile tool, such as BIM Field360, that is

connected with Bluetooth Low Energy system (BLE). All the aforementioned solutions can be grouped in one, driving the software future developments, since they are connected to the software vendors. Construction companies, especially the large companies as BAM, can have a massive impact to enforce those improvements, in order to be in line with their own needs and requirements. At the moment what could BAM do, is stating the necessary modifications of the software to the existing software partners to suit the projects' requirements and ideas as well as scrutinize the offers from the different software vendors prior to agreement, taking also into account the potential improvements elaborated above.

**Enhancing the hardware capabilities**

The next set of solutions are referring to the *hardware improvements* that can be made. According to the interviewees, the company should provide mobile devices that meet certain quality requirements. Providing devices with enough storage capacity and also increased speed that can handle the requirements of the modern software. According to site engineers, a software application, BIM Field 360, is taking up to 80% of the total storage capacity of their mobile device, restricting the use of further applications and also making the device a lot slower. Moreover, every tablet should come along with a good protection case and also a strap around it. As discussed before, the site engineers come across difficult situations on site, having to carry tools and walking around the site. Taking that into account, the users prefer to use the paper forms to avoid the risk of damaging the expensive device. The enhancement of the quality of the hardware to overcome certain technical barriers should be decided during the *preliminary and pre-construction stage*.

**Increasing IT support**

The IT department is also holding a key role to the adoption of the digital site tools. According to the interviewees the *support of IT* in the projects is currently limited regarding the digital site applications. The first thing that IT could do is grant accessibility of certain applications to the site engineers. Currently, there is a sort of nervousness from the IT department to give access to certain software applications, due to lack of trust or extra costs. The IT department should make themselves more accessible to answer any queries that the site users have and deal, consequently, with the complexity of the software. Also, the mobile device should be considered as a standard piece of kit for everyone that works on site and need to capture data. The tablets and mobile phones are present in construction site for quite a long time now, and should be considered equally important to a laptop on the project. Moreover, one of the main problems that the users faced on site, is the limited internet connectivity, which according to the interviewees is serious technical barrier for them. The IT department should provide wireless internet access on the whole site or SIM card on the devices. In cases that the construction site is too large, it is recommended the solution of providing a SIM card to the tablets. Lastly, an adequate support of the IT department to the users is essential. The users, especially the ones with limited digital knowledge, have many enquiries and the IT should be in a position to respond in-time and solve them, by providing on-time services. The increased support of IT should be provided *during the construction stage*.

### 5.3.3 Processes

*Table 6-Processes Solutions*

| Process | | |
|---|---|---|
| **Solutions and potential initiatives from the company** | **Adressed barriers** | **Stage** |
| Setting common goals & requirements | Lack of standardization | Post-Construction |
| Improving the project control reporting system | Unawareness of the benefits | Preliminary |
| Initial set-up of forms & templates | Poor Initial set-up of processes | Pre-Construction |
| Digitizing additional processes | Unawareness of the benefits | Pre-Construction & Construction |
| Promoting a companywide approach | Lack of standardization | Post-Construction |
| | Poor Initial set-up of processes | |
| | Unawareness of the benefits | |

**Setting common goals & requirements**

As emerged from the data collection, the digital transition for site data capture, heavily depends also on the processes. An initial and vital step to improve the company processes is the identification of *common goals and requirements* among different projects and divisions. From the outset of the project, the goals and requirements should be properly identified, decreasing the time wasted by different people collecting unnecessary information. Becoming more collective in terms of the requirements, will enable the generation of a single database of information that will increase the efficiency of people and enhance the understanding of what data needs to be collected and delivered to the client. Within the BAM group, there are plenty of different divisions, both infrastructure and buildings, which has proven quite a barrier for the establishment of common projects' goals. However, as has stated by the digital construction manager of BAM construct this barrier is not insurmountable, "We do have common goals across the business, that are fed through to certain people. Most construction projects have a similar goal to deliver, both civil and buildings, they all have a common thing. And then there is maybe a

20% which is unique to every project. This 20% you would need to do it on the construction site, by customizing the technology or by appointing an expert that could facilitate that change quickly. Apparently there are solutions, but certainly we should first standardize the 80%." A good approach for setting common goals and requirements, is a solid discussion, at first in a divisional level. After the establishment of these common goals on each of the divisions, the establishment of common goals across the organization can follow. Setting common goals and requirements among the group should be sent as feedback after the completion of the project.

**Improving the project control reporting system**

As has been discussed earlier, it is important for the different software to communicate with each other. Connecting the site tool with the division's CDE and also the company's CDE can have a massive impact for the effectiveness of this digital transition. By capturing field data digitally, the site engineer is feeding into one application. This application then should feed other multiple applications for other recipients to view the information and giving the ability to do analytics. The company could then *review the current project control reporting system*. The current system is mainly project-driven and involves a lot of manual operations, in which the project team must manually translate the captured data to feed into other programs. Establishing the common goals and providing the ability that the site tool can automatically import data into other systems, will enable project managers and construction directors to compare projects, analyzing defects and their root-causes, and many other functions that have a huge beneficial impact to the organization success. As stated from the interviewees, 95% of root causes are not filled up because is a difficult manual process for the site team. The company should make sure that has the ability to foresee things, to identify trends and to be preventive. Not only identify the problem but also ensure that it will not happen again. Therefore, the review of the current reporting system is a strong recommendation to the company. The reporting system should be driven from the construction directors. Construction directors should set the strategy and inform the sites what needs to be reported in order to have a common basis for comparison and monitoring. In terms, of adding more information for the "bigger picture", an upscaling is required, because data relies on people to input. Having the right process to input that information is required. For enhancing the current project control reporting system, BAM has started to use the "Power BI" Microsoft software. Nevertheless, it is a semi-automated process because the data should be first exported into an Excel format from the site tool, yet is an easy way to create dashboards and providing a solid reporting system to the top management level of the company. The review of the project control reporting system should be implemented *after the construction stage.*

**Initial set-up of forms and templates**

Currently, there is a huge amount of generic checklists/templates for almost every conceivable type of construction. Hence, it becomes extremely difficult for the system to adopt. The administration and site time required is extremely vast and proves to be too much of a burden to be able to actually do it effectively. Reducing the number of checklists would give the chance to the company to focus only on the important aspects that will cause severe rework and costs to be repaired and must not be overlooked. Carrying out a sort of risk assessment review of a project from a quality perspective will bring to the surface only the most vulnerable parts of that projects that are going to bear the biggest risk from a quality point of view. In that way, the checklists will

become more meaningful and valuable, decreasing in number at the same time. *Should be decided pre-construction*.

**Digitizing additional processes**

Furthermore, *digitizing more processes* will ultimately drive more people to come on board and spread the adoption of mobile site management applications. Currently in BAM projects, the processes that have been mainly digitized are the quality control and snagging. Involving more processes being done through the site tools is an aspect that the company should seriously investigate. Processes that should be automated and digitized are for example, the tracking of activities' progress, safety reporting, material and equipment tracking, material delivery tickets, payments of subcontractors and many more. In that way, more and more people could see the benefits of this digital site data capture. Should be initiated *during pre-construction* and be done *during construction*.

**Promoting a companywide approach**

Site management is a massive area for every contractor company and can support a lot of different departments if it is implemented correctly. Combining the four recommendations discussed above, the common goals, the reporting system, the set-up of forms and the digitization of more processes can ultimately enable the company to promote a *companywide approach for capturing site data*. Promoting a companywide approach could be proven an important 'tool' to help the company overcome the barriers of the lack of standardization, the poor initial set-up of processes and the unawareness of the benefits. This approach can be standardized into a high degree, however certain customizations by region/business line among the group are inevitable. An additional obstacle to this standardization is also the lack of a software site tool that can support all the processes. Therefore, it is recommended that the company shares the best practices for implementing different processes, in order to be adopted and standardized for the whole group until technology catches up.. The generation of the approach should be done *post-construction* after the evaluation of the projects.

## 5.4 Digital mobile site management RoadMap

The aim of the roadmap is to provide a solid sequence of the actions and recommendations for the company, in order to successfully digitalize the site management process and acquire the maximum benefits. This sub-chapter aims to give answers to the 5th research question

### 5.4.1 Creating the implementation RoadMap

For the creation of the roadmap, the methodology described in the 3rd chapter will be followed:

**A. Deciding the type of the proposed solution**

In the previous sub-chapter, the solutions were divided into three categories: people, technology process. This categorization derived from the thematic analysis of the interviews' content and it was part of the original categorization. The following figure is depicting this categorization, for the easier comprehension of the reader.

| People | Technology | Process |
|---|---|---|
| • Increasing the awareness<br>• Modifying the HR Development plan<br>• Establishing a user evaluation system<br>• Enhancing the training scheme<br>• Promoting the benefits<br>• Involving the supply-chain and pr. manager<br>• Taking away the alterantives | • Access to internet<br>• Increased IT Support<br>• Simplifying the user-interface<br>• Software accessible to all mobile devices<br>• Enhancing the hardware capabilities | • Setting common goals & requirements<br>• Digitizing additional processes<br>• Improving the project control reporting system<br>• Initial set-up of forms & templates<br>• Promoting a companywide approach |

*Figure 16- Type of solutions*

**B. Deciding the stage of the proposed solution**

In this step, all the solutions are categorized according to the stage that is most suitable to be put into practice, as has been implemented previously. This categorization was deliberately selected from the author, prior to the thematic analysis of the interviews. Therefore, the interviewees were specifically asked at which stage it is best for the proposed solutions to be taken.

*Table 7-Solutions categorized by stages*

| Preliminary | Pre-Construction | Construction | Post-Construction |
|---|---|---|---|
| **Enhancing the existing training scheme** | | **IT Support** | **Promoting a common approach** |
| **HR Development plan** | **Increasing the awareness** | **Promoting the benefits** | |
| **User Evaluation system** | **Involving the supply-chain and pr.manager** | | |
| **Taking away the alternatives** | **Initial set-up of forms and templates** | | |
| **Improving the project control reporting system** | **Setting common-goals & requirements** | | |
| **Enhancing hardware capabilities** | | | |
| **Simplifying the user-interface** | | | |
| **Driving the software developments** | **Digitizing additional processes** | | |

**C. Establishing the most impactful actions (solutions)**

As described in the methodology (chapter 3), in this step the importance of the proposed solutions will be decided and divided into three categories: High, Medium and Low.

Deriving from the interviews and the figure 14, the six solutions that had the most responses will be allocated in the category 'high importance, the next 5 in the category 'medium importance' and the last 5 in the category 'low importance'. The following table, shows the solutions as divided by the level of importance, as derived from the outcome of the case-study interviews.

*Table 8-Level of importance (Solutions*

| Solutions | Level of Importance |
|---|---|
| Promoting a common approach | HIGH |
| Promoting the benefits | |
| Increasing the IT support | |
| Simplifying the user interface | |
| Initial set-up of forms & templates | |
| Taking away the alternatives | |
| Enhancing the existing training | MEDIUM |
| Increasing the awareness | |
| Involving the supply chain & Pr. Manager | |
| Setting common goals & requirements | |
| Driving the software developments | |
| Enhancing the hardware capabilities | LOW |
| Establishing a user evaluation system | |
| Digitizing additional processes | |
| Improving the project control reporting system | |
| Modifying the HR development plan | |

The table shows what solutions are considered as high, medium and low importance. At this point, it will be elaborated what does it really this level of importance mean, for the Royal BAM Group, but also for every other construction company willing to boost the adoption of the mobile digital management tools in their projects.

- *High-Importance Solutions:*

The solutions on this category should be considered as the most impactful initiatives that the company could take in order to boost the digitalization of site management. In other words, these solutions should be set as a high priority by the company and is expected to influence greatly the adoption of the mobile digital tools.

- *Medium-Importance Solutions:*

In this category, the solutions is expected to have a medium effect on the company's objective to digitalize the construction site management.

- *Low-Importance Solutions*

The potential initiatives were selected from the interviewees and the data analysis, as the least likely initiatives to have an impact on boosting the adoption. The company should consider these solutions as low priority and focus more on the other solutions.

### D. Digital site management implementation Roadmap

In this sub-chapter, the roadmap for successfully digitalizing the site management process will be presented. Moreover, an explanation of this roadmap will be provided as well as a validation from the vendor digital construction manager of the Royal BAM. The roadmap contains three different dimensions of the potential solutions (actions) that were identified previously in this 5th chapter.

The three dimensions of the roadmap are:

1) Key Drivers
2) Time
3) Importance

The roadmap is presented in the next figure:

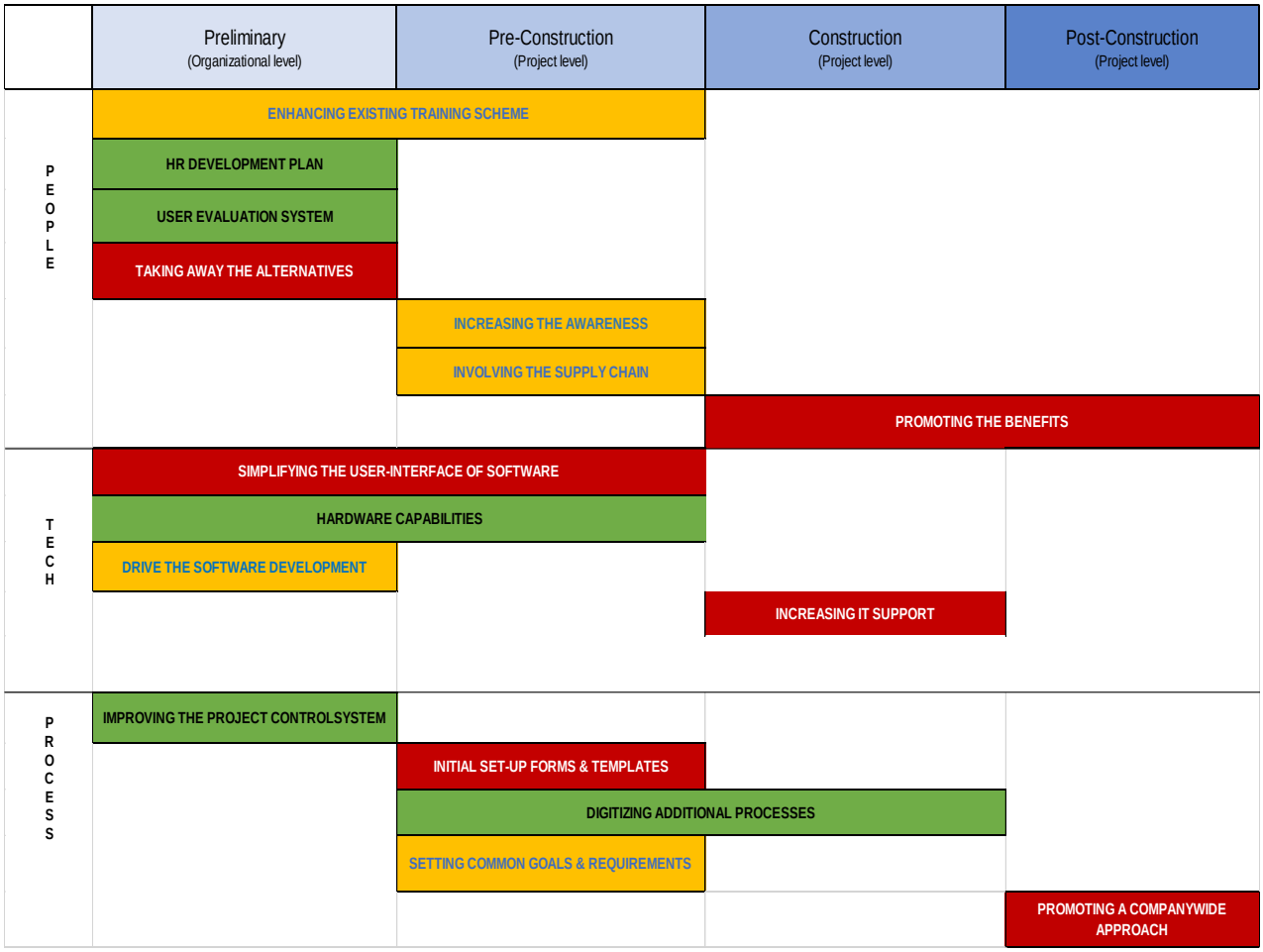



*Figure 17 -Implementation Roadmap*

### 5.4.2 Explanation of the implementation RoadMap

The implementation RoadMap characterizes the set of initiatives according to their type, their stage and their level of importance. The purpose is to provide an effective and sequenced representation of those actions, for an easier and more accurate implementation by the company, to boost the adoption of the digital mobile management tools. A stage-by-stage explanation of the roadmap will now be elaborated, in order to provide a successful path to the company towards the digitalization of the site management.

The first stage (Preliminary stage), it is recommended that the company take away the alternatives and state as a sole option the use of the digital tools to capture site data. This action has to be taken in the beginning, as it is important that the tender stage is tailored according to this requirement. Also, driving the software developments is an initiative that regards the organizational decision-making. Moreover, additional initiatives in this stage could be the modification of the HR development plan, improving the project control reporting system and the establishment of a user-evaluation system. However, as seen in the RoadMap, there is less possibility that these 3 actions can have as high impact comparing to taking away the alternatives.

In the pre-construction stage, when the design, planning and tendering of the upcoming project take place, the company should first consider to standardize the set-up of forms and templates. Revising the previous templates adopted in previous projects and ultimately choosing the most suitable for the particular project, could save significant time from creating new templates from the start and increase the accuracy of the digital site data collection, as only the necessary data can be captured. It is important these common templates to be in line with the goals & requirements of the projects. Next to that, the company can motivate the project managers and digital construction managers to spread and explain the necessity of the digital site data capture before the construction starts as well as to try to involve more disciplines of the supply chain into the digital process. Three more initiatives can also be considered by the company and should be put into effect in both stages, preliminary and pre-construction. The purpose of this is that the consideration from the organizational level, precedes the actual implementation. More specifically, the modification of the existing training scheme should be decided prior to the commencement of a project, however the actual adjustments and effect should take place in pre-construction and tailored in full detail according to the project goals and requirements. Similarly, simplifying the user interface and providing better hardware, is actions that the company should decide for all the projects as a general strategy, but the actual selection is during the tender & planning stage. Therefore, the company should make sure that the selection during pre-construction is in line with the strategic decisions regarding these two initiatives.

The next stage refers to the construction stage, where the on-site activities take place. In the coal face of the construction, there are two initiatives that according to the RoadMap should be regarded as a high priority by the company. As discussed in previous chapter, promoting the benefits can be done with various ways. For example, motivate people to communicate the benefits of the digital site data capture among the users. A foreman needs to see the practical benefits of the digital way, from another foreman as he is not interested about the benefits from

a planning or design side of view. To this extent, the company could also conduct case-studies to monitor and measure the actual tangible benefits of the digital site data capture comparing to the traditional way. Measuring the time and cost saved during the on-site activities, using perhaps the measuring template developed by the author (Appendix C), could persuade the board, client, supply-chain but also the actual end-users to use the digital mobile tools. The other important initiative during this stage is the support from the IT department. The IT department should make themselves more accessible to answer any queries that the end-users might have and support them more drastically with any problems that they face during the use of the digital tools on their on-site activities.

After the completion of the construction of the project, is important the evaluation of the impact of the digital mobile tools in order to identify common problem areas, success areas and what were the reasons in each of these two cases. The ultimate outcome of this post-evaluation is the promotion of a companywide approach for site data capture.

### 5.4.3 Validation of the RoadMap

After the presentation and explanation of the RoadMap above, the author shared the output with the deployment digital construction expert of Royal BAM, Mark Taylor. The interviewee is responsible for the communication with the software developers as well as leading the BAM's work-package 'Site Data Capture'. Therefore, he can be considered as the most suitable expert for discussing, evaluating and potentially validating the final output of the study, the RoadMap. The deployment expert was asked to share his insights regarding the specific initiatives that derived from the case-study and their importance. The discussion with the decision-maker was to provide more insight and a potential validation, and not altering the final recommendations (RoadMap) to the company, since the primary source of data is the case-study. At this point, it should be stated that the other 2 dimensions (type of initiatives and stage), were in line with the expert's view and no differences came up.

For the validation of the importance of the suggested initiatives, the deployment expert was asked to rank the initiatives that have the biggest impact based on his personal views and experience. The following table depicts the level of importance of the initiatives, as derived from the expert's ranking.

*Table 9-Ranking of solution (Deployment Expert)*

| Deployment Expert's Ranking of Initiatives | |
|---|---|
| 1 | Promoting a common approach |
| 2 | Promoting the benefits |
| 3 | Drive the software developments |
| 4 | Increased IT support |
| 5 | Simplifying the user-interface |
| 6 | Increasing the awareness |
| 7 | Enhancing the existing training |
| 8 | Taking away the alternatives |
| 9 | Initial set-up forms & templates |
| 10 | Involving the supply-chain |
| 11 | Setting common goals & requirements |
| 12 | Digitizing additional processes |
| 13 | Establishing a user evaluation system |
| 14 | Improving the project control reporting system |
| 15 | Modifying the HR development plan |
| 16 | Enhancing the hardware capabilities |

Moreover, the output from the expert will be compared with the output of the case-study. Hence, the identification of potential differences becomes possible and will be discussed. The following table depicts the solutions' importance as derived from the case-study and from the deployment expert.

*Table 10-Level of importance derived from case-study and expert*

| Solutions | Level of Importance | |
|---|---|---|
| | Case-Study | Deployment Expert |
| Promoting a common approach | | |
| Promoting the benefits | | |
| Increasing the IT support | | |
| Simplifying the user interface | | |
| Initial set-up of forms & templates | | |
| Taking away the alternatives | | |
| Enhancing the existing training | | |
| Increasing the awareness | | |
| Involving the supply chain & Pr. Manager | | |
| Setting common goals & requirements | | |
| Drive the software developments | | |
| Enhancing the hardware capabilities | | |
| Establishing a user evaluation system | | |
| Digitizing additional processes | | |
| Improving the project control reporting system | | |
| Modifying the HR development plan | | |

As it can be seen from the table, the level of importance of the solutions is almost the same in both cases, since the final outcome of the study is validated. However, 4 specific differences emerged from the ranking and discussion of the deployment expert. The first difference, refers to the proposed solution 'increasing the awareness'. According to the deployment expert, 'this initiative should be considered as a high priority for the company in order to boost the adoption of the digital mobile tools. Project-based people, perhaps, do not really understand why is important for the company to have the site data in a digital format, and that is perhaps the reason that has not emerged as a high important solution from the case-study'. Moreover, the expert considered that 'driving the software developments' as a company, is also a really important action and is also his main responsibility and role within Royal BAM. The third difference identified from the table 10, has to do with 'taking away the alternatives'. Comparing to the case-study results, the expert considers it as an extreme action because imposing the digital way can have an opposite effect on motivating the project-based people to use the digital tools. Additionally, the company's processes are not yet fully established to support such an action in all of the projects. The final difference was allocated in the 'initial set-up of forms & templates'. The deployment expert, considers that at this point standardizing the company's checklists and forms across all the different operating companies is an action that is not feasible at the moment. However, he agreed that such an initiative can have an important impact to the adoption, if achieved. Apart from the differences, the discussion with the expert brought into the surface a really important similarity. As we can see from both the results, case-study and deployment expert, the solution 'promoting a common approach' is the solution that is considered to have the biggest impact to the company. The importance of this solution urged the author to investigate it in more depth and offer a more practical suggestion to the company for the successful implementation of this suggested solution. To this extent, a standardization model will be developed below, that depicts how the company can reach a standardized and unified approach for all of the its' projects.

### 5.4.4 First partial implementation of the RoadMap

***Creating a model for standardizing a common approach***

Regarding the proposed solutions that derived from the interviews, in terms of the driver "process", it can be seen that the adoption of a companywide approach for capturing site data is mainly a combination of all the aforementioned "process-solutions". Taking a step further from the original research objective, the author feels that he can contribute more to the company, and potentially to the industry, by presenting a model that can achieve the standardization of a common approach, by combining all the solutions in the sub-chapter 'process', and boost even further the possible adoption of the mobile digital site management tools and digitalization of the site management. It is important to be mentioned, that this model is contributing to accomplish the proposed solution "companywide approach for capturing site data" and is regarded as a practical recommendation for the solution 'creating a common approach' and a first partial implementation of the RoadMap, and should not be considered as the final outcome of the research, which is the RoadMap. The standardization model will be presented and discussed below:

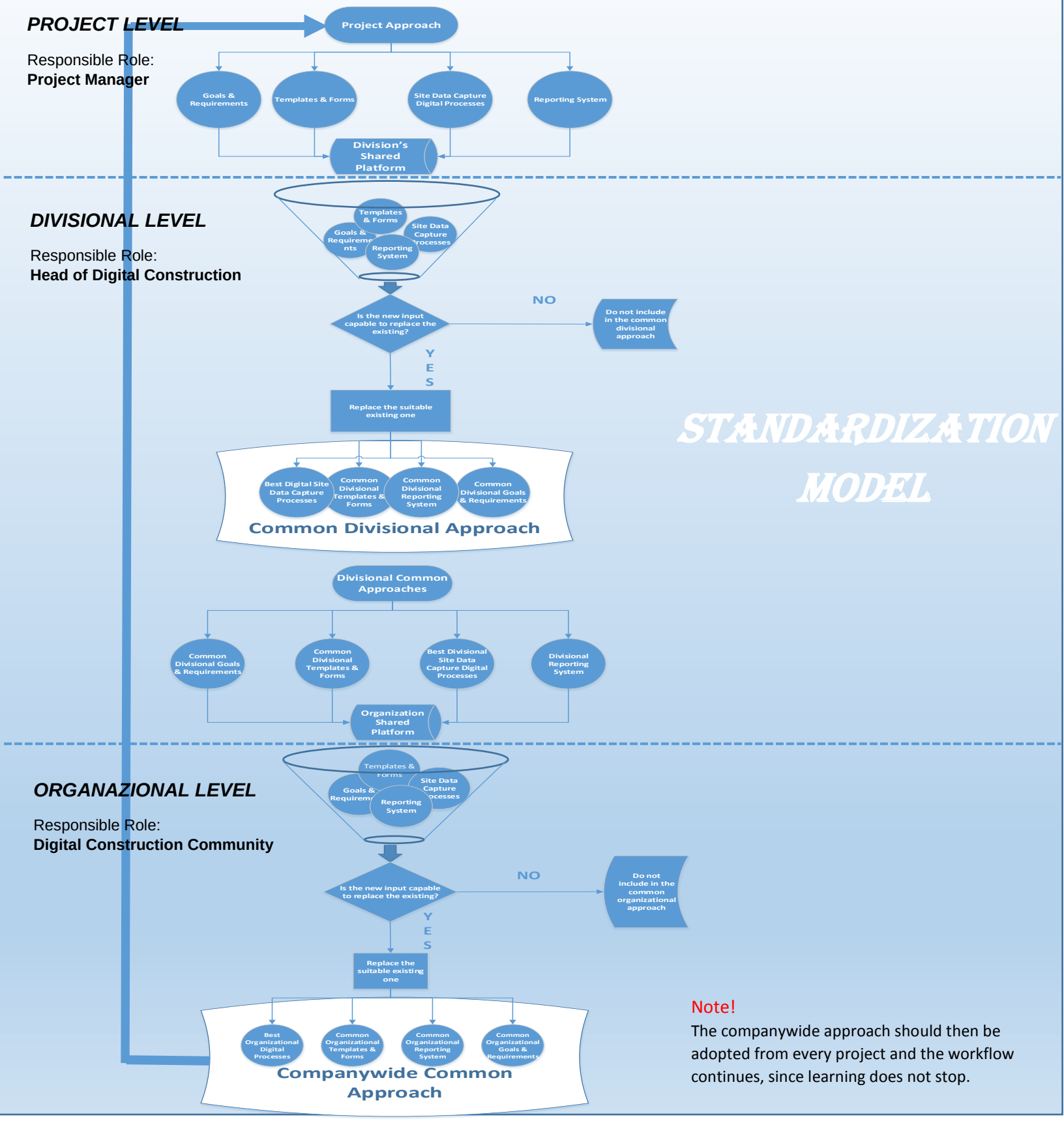



*Figure 18-Standardization Model*

In essence, this model constitutes a continual improvement loop. Developing a central knowledge repository for sharing information across all company's projects, that will enable all the organization to share experience and knowledge. Similar to the original lean manufacturing process, any assembly line worker could stop the assembly line and offer an improvement idea to management.

**Project level**

Beginning from a project level, every project can upload in the division's shared platform the general impact of using site digital tools in each of the categories. it is important to be provided a small description of the processes, that have been followed, supporting it (if possible) with the calculation of tangible benefits. For the 3 site management processes (progress, quality, material & equipment), the measuring template developed in the present study can be utilized for the calculations. However, is important for projects to share all the site management processes that transformed into digital ones, regardless the importance of these processes. Thus, the management can evaluate and identify the 'best practices' among all the projects of the Royal BAM Group. Moreover, it is important for projects to share and upload the digital forms and templates that they have created and utilized, in order for next projects to avoid extra effort and with an end goal to be the same (or almost the same) for all future projects. Additionally, sharing feedback regarding the goals & requirements that the projects had, will offer a huge boost to the company to adjust and establish the common strategy. By setting common goals, it becomes more possible and easier the enhancement of the current project control reporting system. Finally, it is crucial for the successful deployment of the model, that the project teams also share their bad experiences, the processes that did not meet the required goals and also potential recommendations to the group. The person responsible for uploading the aforementioned input is the project manager of each project.

**Divisional level**

This feedback from the projects, will give the chance to the division to evaluate the effect of digital tools on site, what can be improved, what it can be standardized in order to set a common strategy for the division. From this point, every division can evaluate the feedback from projects and filter the newly entered input. After this filtering, then the division can gradually select the best practices, set common opco goals, reporting system and adopt a common approach. The selection of what should be included in every division's common approach should be decided from the head of digital construction department of every different division of the group.

**Organizational level**

Following, the standardization of every division's strategy, the top management level of the organization can then evaluate these divisional strategies and compare them Thereafter, the whole organization can evaluate the different division common strategies and, similarly with the previous method, come up to a companywide approach for the site data capture and reporting. The final decisions for the development of the companywide approach should be discussed and chosen from the top digital construction experts of the group (Digital Construction Community).

The model should be dynamic and the loop continuous. Every potential improvement should be evaluated and can replace the existing one. The evaluation of potential improvements should be conducted by the top management level of the company. Should be decided by the head of the digital construction of this division.

A first implementation of the standardization model was made by the author during the visit on multiple projects of BAM in the UK. The best practices from these projects were identified, along with descriptions, benefits and future recommendations. The reason was to present to the company an effective way for sharing the "best practices" in order to get the maximum value of the model. The outcome is provided in the appendix D. However, for the correct implementation of the model, sharing only the best practices will not prove enough. The projects should also share all the different aspects that were stated before and were included in the model.

# 6. Scientific contribution, limitations and future research

## 6.1 Scientific Contribution

The value of this research is associated with the extent it contributes to the present academia and will be discussed below:

**A. Identification of the top benefits from the use of the digital mobile tools**

The vast majority of the existing literature has focused on proving the benefits of digital construction in the design stages. This study has proved the important benefits for the industry, that can derive from the adoption of digitizing the site management.

**B. Identification of the main barriers**

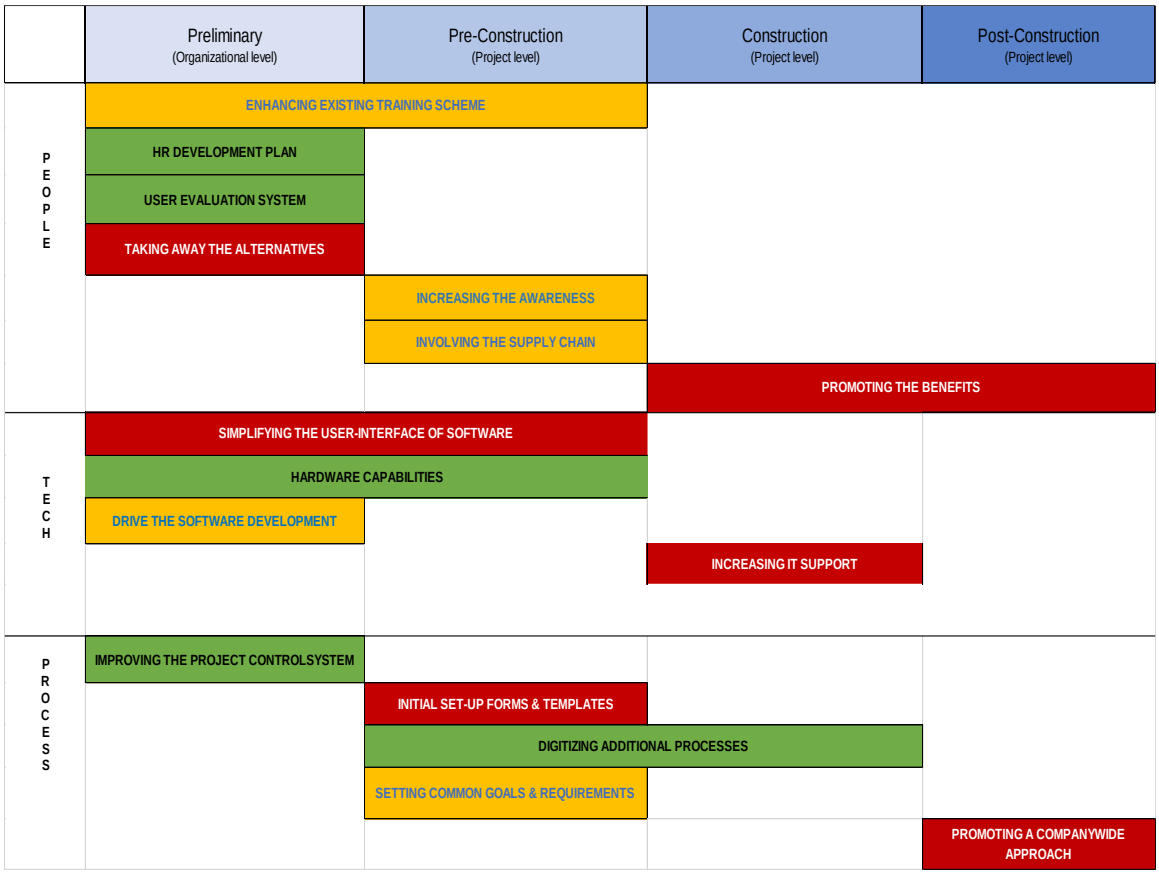
By visiting multiple projects and conducting a great amount of interviews, the author acquired several implementation barriers from different roles. The existing literature and research was mainly focusing on investigating the barriers from the point of the top management level or the digital construction managers. Straying from this path, this study gave the ground also to the site users to talk extensively for the problems that they face. Given that the true barrier and driver is the people; their input was extremely important for the achievement of the research objective.

**C. Identification of solutions**

Important recommendation for the existing research was established on how we could boost the adoption of mobile digital application on-site activities. Moreover, the solutions were driven by 3 different aspects (people, technology, process), simplifying the actions that need to be taken. Apart from the object of the study which was the uptake of digital technology on the site data management, this categorization and approach can also be adopted for boosting the uptake of different digital technology in the future research.

**D. Development of a roadmap to overcome the barriers**

This research contributes to academic knowledge by producing a roadmap that guides construction companies on how to successfully adopt the digital approach for managing the site. The roadmap is a powerful tool, for every company that want to utilize this technology and maximize their chance of achieving the desired benefits instead of wasting time and effort by continuing operating with the traditional paper-methods.




## 6.2 Main research limitations

During this research, certain limitations arose regarding the data collection. The author developed a measuring template for quantifying the tangible benefits of the use of mobile management applications. From the eight projects of the multiple case-study, no project could provide the author with calculations, as the project teams were quite busy with their tasks and completing the projects. However, 2 other projects have already provided the author with some tangible benefits, that are presented in the appendix C.

Due to the nature of the case study, one limitation has to do with the choice of Royal BAM as a single data source. The company's size, type and location can potentially play a role in the reliability of the research outcomes. The benefits, the barriers and the solutions emerged from the interviews and observations within BAM projects. For example, in the development of the

'digital-supported model' it refers to an organization that entails smaller divisions/business units. Smaller companies could still use the model, by skipping the middle step.

Another limitation derived from the study, is the sole focus from a contractor's perspective. The benefits, barriers and solutions are focusing on a large contractor company. The results are not fully compatible for a client or for a manufacturer, however in some cases, they could valuable insight about the potential of digitized site data capture for their businesses as well.

The projects that were studies within Royal BAM Group, all belonged to two operating companies of the group, BAM Nuttall and BAM Construct. Hence, not all the different operating companies of the group were covered in the case-study.

Lastly, another limitation had to with the language barrier. Royal BAM Group is an international organization with operating companies across Europe and projects across the world. The author could only have discussion with English-speaking projects and in some cases with Dutch-speaking projects.

## 6.3 Future research

Taking into account this study's limitations in terms of data availability, it would be interesting for future research to enhance this study. Using the measurement template developed on this study, future researchers could monitor certain projects for an extended period (perhaps until completion) and produce a precise calculation of the ROI, based on real-life monitoring and counting. What it would be also interesting, is the correlation between the ROI, or other benefits of the digital mobile tools, and different metrics. Metrics such as the project size, delivery methods, BIM maturity and different type of projects.

As a potential future research, the investigation of additional applications of digital technology on site, is strongly recommended. In the present study, the mobile devices and the cloud software were studied. Future researchers could dive into the most advanced digital technology site tools, such RFID tags, machine-guidance technologies, VR & AR and more.

It would also be interesting to further investigate the extent to which efficiency gains vary between different types of construction management staff based on job description (i.e. site engineers, planner, project manager, site managers) to determine if certain site personnel who devote most of their time to tasks not affected significantly by the digital site data capture, so as not to invest training time and resources on this staff.

Complementary to the present work could also be the digitization of additional site management processes. In the present study, the processes of progress tracking, quality control and equipment tracking were investigated. Investigating other processes such as on-site safety control, material tracking and procurement tracking, could prove really beneficial for the industry. Providing also the benefits (tangible & intangible), requirements, recommendations and how this processes are enhanced through digitization is also crucial for boosting their adoption. The pattern followed in the present study can be followed for this purpose.

# 7. Conclusions

The objective of this research was to provide construction companies an overview about the benefits, the implementation barriers as well as providing a solid and detailed approach to overcome those barriers in order to get the maximum of the use of digital mobile site management tools. In light of the information gathered by the literature review and the case-study, it can be concluded that digital mobile site management applications should be preferred over the traditional paper-methods. A well-implemented digital process for capturing site data can provide important benefits and be a solution to the main problem of construction industry, the low productivity. The dissertation managed to give answers to the basic research questions. More specifically:

1. *What are the main benefits that derive from the use of digital mobile data management tools, from a contractor's perspective?*

The case-study method adopted in this dissertation, included 35 interviews with individuals that gave valuable insight regarding the benefits that they perceive while using mobile digital tools. Specifically, eight main benefits derived from the interviews that were discussed and analyzed in previous chapter. These benefits were: 1) Increased efficiency, 2) Enhanced information flow, 3) Improved Quality, 4) Transparency, 5) Job satisfaction & well-being, 6) Adding Value to the company 7) Client satisfaction and 8) Decreased Paperwork.

2. *What are the main challenges, related to the utilization of digital tools on-site, faced by a large contractor's organization?*

The main reasons that discourage people to embrace this new technology were identified through the interviews with different roles within the company. What is worth mentioned is that the top barrier is the physical & technical barriers. In other words, people tend to be discouraged by the limitations of the tools themselves. Moreover, a really important blocker to adoption proved to be the cultural and age difference. Through the interviews it emerged that people with high experience have get used to the traditional methods and are resistant to change. The rest of the implementation barriers are: Poor information exchange, Initial investment, Lack of skills, Lack of standardized approach, Unawareness of the benefits and Complexity of the software.

*3. What are potential recommendations or strategies needed in order to overcome the implementation barriers?*

The results of the interviews have led to three different patterns, in terms of the solutions. These patterns were categorized into people, technology, process and have been named the 3 key main drivers for boosting the adoption of site digital tools. The first main driver, and probably the most crucial, is the people. To motivate people and take them on-board with this new technology, the company can take plenty of actions from enhancing the existing training scheme until imposing the use of these tools. In terms of the technology, it is strongly recommended to the company to communicate the needs and requirements of the projects with the software vendors, in order to adapt and evolve their products. A large company as BAM, can drive and impact the decisions of software vendors. Lastly, in terms of processes, the common goals have to be set in order for BAM to reach a certain level of standardization and promoting a companywide approach for digital site data capture.

*4. How can the possible solutions and recommendations be mapped, in order to be easier implemented by the company?*

The solutions were analyzed in three different dimensions (drivers, time, importance). Deriving from these analysis, then the solutions were mapped into a implementation roadmap that can constitute as a key strategy for the adoption of digital mobile management tools. Thereafter a validation was achieved with the aid of the digital deployment expert of the Royal BAM Group. Finally, given the urgency and the importance of 'promoting a standardized approach' for the company, a digital standardization model was created, in order to successfully lead the way to reach a certain level of standardization and boost the adoption of mobile digital tools among projects.

**As a general comment to the construction industry**

"We should become more technological savvy on the field before implementing all this new digital technology. People should try and first do the basics, regarding the processes and how they can execute them more efficiently. The content of this thesis, mainly focuses on how the companies could successfully turn their traditional site data capture processes into digital effective ones. Accomplishing that, and by getting all the site personnel on-board with technology (in the beginning getting them to use mobile devices), the fully-digitalized construction projects will sooner be achieved

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# Appendices

## Appendix A. Search Process (Table 11)

| Source Code | Reference | Type | Type Source | Search Term | Source | Hits | Search Field |
|---|---|---|---|---|---|---|---|
| 1 | Abanda, F.H., Oti A., & Manjia, M.B., (2018). | Article | Applied System Innovation | Construction Site Management | Google/ Scholar | 3,700,000 | Construction Management |
| 2 | Azhar, S. (2011). | Article | Leadership and Management in Engineering | Definition of BIM | Google/ Scholar | 63,400 | Digital Construction |
| 3 | Bakis, N., Kagioglou, M., Aouad, G. (2006) | Conference Paper | 3rd International SCRI Symposium, Salford Centre for Research and | Benefits of digital construction management | Google/ Scholar | 872,000 | Digital Construction |
| 4 | Banna, Matt. (2017) | Internet article | KaiNexus Blog | Lean Construction | Google/ Scholar | 322000 | Automation in Construction |
| 5 | Bassioni H A, Price A D and Hassan T M (2005). | Article | Construction Management & Economics | Benefits of digital construction management | Google/ Scholar | 872,000 | Construction Management |
| 6 | Barlish, K., & Sullivan, K. (2012). | Artcile | Automation in Construction | Benefits of digital construction management | Google/ Scholar | 872,000 | Automation in Construction |
| 7 | Berg, P. et al. (2014). | Conference Paper | LCI Congress 2014 Presentation | Mobile Devices in Construction | Google/ Scholar | 2,100,000 | Automation in Construction |
| 8 | Becerik-Gerber B, Rice S (2010) | Article | Information Technology in Construction (Itcon) | BIM application in construction management | Google/ Scholar | 40,100 | Construction Management |
| 9 | Becerik B. and Pollalis S. N. (2006) | Article | Design and Technology Report Series | BIM application in construction management | Google/ Scholar | 40,101 | Construction Management |
| 10 | Bryde, A. Broquetas, M. & Volm, J (2012). | Article | Project Management | Construction Site Management | Google/ Scholar | 3,700,000 | Construction Management |
| 11 | Chelson, D. (2010). | Master Thesis | University of Maryland | Site-BIM | Google/ Scholar | 453 | Automation in Construction |
| 12 | Chen, Yuan, and John M. Kamara. (2011) | Article | Automation in Construction | Digital site management | Google/ Scholar | 1,730,000 | Automation in Construction |
| 13 | Dossick, C.S. & Neff, G. 2011 | Article | The Engineering Project Organization Journal | BIM application in construction management | Google/ Scholar | 40,100 | Construction Management |
| 14 | Davies R. and Harty C. (2013) | Article | Automation in Construction | Site-BIM | Google/ Scholar | 453 | Automation in Construction |
| 15 | Eastman, C., Teichol, P., Sacks, R., & Liston, K. (2011) | Book | Wiley&Sons | Definition of BIM | Google/ Scholar | 63,400 | Digital Construction |
| 16 | Ghauri, P. and Gronhaug, K. (2010) | Article | Scientific Research | Research Methodology | Google/ Scholar | 3.452.000 | Research Methodology |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 17 | Guest, G., Bunce, A., & Johnson, L. (2006). | Article | Field Methods, SAGE | Research Methodology | Google/ Scholar | 3.452.001 | Research Methodology |
| 18 | Hardin, B. (2015) | Book | Wiley&Sons | BIM application in construction management | Google/ Scholar | 40,100 | Construction Management |
| 19 | Hartmann, A. (2017) | e-Book | Wiley | Research Methodology | Google/ Scholar | 3.452.000 | Research Methodology |
| 20 | Harstad, E. Lædre, O. Svalestuen, & F. Skhmot, N. (2015). | Conference Paper | Proc. 23rd Ann. Conf. of the Int'l. Group for Lean Construction. | Mobile Devices in Construction | Google/ Scholar | 2,100,000 | Automation in Construction |
| 21 | Hergunsel, M. (2011). | Master Thesis | Worcester Polytechnic Institute | Benefits of digital construction management | Google/ Scholar | 872,000 | Digital Construction |
| 22 | Jian, L (2015) | Article | Philosophy of the Social Sciences, | Benefits of digital construction management | Google/ Scholar | 872,000 | Digital Construction |
| 23 | Koskela, Lauri. (2005) | Conference Paper | Annual Conference of the International Group for Lean Construction | Lean Construction | Google/ Scholar | 322,000 | Automation in Construction |
| 24 | McGraw Hill Construction (2009) | Report | | BIM application in construction management | Google/ Scholar | 40,100 | Construction Management |
| 25 | Mansson, D. W., Hampson, K. D., Lindahl, G.A., & Sanchez, A. X. (2016). | Conference Paper | CIB World Building Congress 2016 | BIM application in construction management | Google/ Scholar | 40,101 | Construction Management |
| 26 | Moran, M. S., (2012). | Master Thesis | TU Delft | Mobile digital management tools | Google/ Scholar | 685,000 | Automation in Construction |
| 27 | Peter Demian & David Walters (2013): | Article | Construction Management and Economics | Digital Construction on site activities | Google/ Scholar | 1,630,000 | Digital Construction |
| 28 | Poirier, A., Staub-French, S., & Forgues, D., (2015). | Article | Canadian Journal of Civil Engineering | Benefits of digital construction management | Google/ Scholar | 872,000 | Digital Construction |
| 29 | Rebolj, D. and Menzel, K., (2004). | Article | Electronic Journal of Information Technology in Construction | Digital Construction on site activities | Google/ Scholar | 1,630,000 | Digital Construction |
| 30 | Renzi, F. V., (2018) | Master Thesis | Structural and Construction Engineering. University of Barcelona | BIM application in construction management | Google/ Scholar | 40,100 | Construction Management |
| 31 | Sacks, R., Radosavljevic, M., Barack, R. (2010) | Article | Automation in Construction | Cloud/Mobile BIM | Google/ Scholar | 47 | Automation in Construction |
| 32 | Salih, S. (2011) | Master Thesis | Real Estate and Construction management. Stockholm | Benefits of digital construction management | Google/ Scholar | 872,000 | Digital Construction |
| 33 | Sattineni, A., and Schmidt, T., (2015) | Article | Procedia Engineering | Mobile Devices in Construction | Google/ Scholar | 2,100,000 | Automation in Construction |
| 34 | Singh J., Mangal M., and Cheng J.C.P. (2017) | Conference Paper | Proc. Lean & Computing in Construction Congress (LC3) | Mobile digital management tools | Google/ Scholar | 685,000 | Automation in Construction |
| 35 | Succar, B (2010) | Conference Paper | Proceedings of CIB World Congress | BIM application in construction management | Google/ Scholar | 40,100 | Construction Management |
| 36 | Smith, J. A., & Osborn, M. (2003) | Article | Qualitative Psychology: A Practical Guide to Methods | Research Methodology | Google/ Scholar | 3.452.001 | Research Methodology |

# Appendix B.

## Templates for savings calculations (Progress, Quality, Material & Equipment) (Table 12)

| bam | A. Progress control | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Main applications/uses | Methods/tools/software applications | Qauntifiable Benefits | Metrics | Manhours | | | | | Materials |
| | | | | Role | Time saved (h/week) | Internal hourly rate (€/h) | Number of people (n) | Duration (week) | material savings (€/week) |
| 1. Measuring / tracking the construction progress | | Enhanced monitoring and documentation of the construction progress | a. Time saved for recording and documenting the tasks' progress | | | | | | |
| | | | b. Time saved to quantify productivity levels and generating the productivity reports | | | | | | |
| | | | c. Costs that are saved and generated from traveling from office to site and back | | | | | | |
| | | | Total saving | | | | | | |
| 2. Analyzing, sharing and updating the progress of the project | | Improved information flow of the construction progress | a. Time saved for storing progress data and generating daily reports | | | | | | |
| | | | b. Time saved for sharing the recorded data among the project members | | | | | | |
| | | | c. Costs saved for sharing this data (printing, shipping, etc.) | | | | | | |
| | | | d. Costs saved that are generated from traveling from office to site and back | | | | | | |
| | | Improved coordination and update of the project members | a. Time for planner to update schedule (CP) | | | | | | |
| | | | b. Time saved to communicate for upcoming activities with the subcontractors | | | | | | |
| | | | c. Time saved on resolving conflicts and communicating between subcontractors and projectmanager | | | | | | |
| | | | d. Time saved on planning next weeks construction- and installation activities | | | | | | |
| | | Adjust schedules in real time based on site feedback | a. Time saved on reworks inflicted by schedule conflicts | | | | | | |
| | | | b. Costs of materials saved on rework inflicted by schedule conflicts | | | | | | |
| 3. Report owner on construction progress & delivery timelines | | Enhanced communication with the owner | a. Reduction in time for communicating and updating the owner over the tasks progress | | | | | | |
| 4. Monitoring Workspace Interfaces | | Reduction in reworks due to time-space conflicts | a. Time saved on rework inflicted by time-space conflicts | | | | | | |
| | | | b. Costs saved on materials for rework inflicted by time-space conflicts | | | | | | |
| | | | Total saving | | | | | | |

## B. Quality Control (Checklists, Punchlists)

| Main applications/uses | Methods/tools/software applications | Benefits | Metrics | Manhours | | | | | Matrials |
|---|---|---|---|---|---|---|---|---|---|
| | | | | Role | Time saved (h/week) | Internal hourly rate (€/h) | Number of people (n) | Duration (week) | material savings (€/week) |
| 1. Measuring / assesing the quality | | Improved product quality inspections | a. Time saved generating QA/QC check-lists | | | | | | |
| | | | b. Time saved for identifying different issues | | | | | | |
| | | | c. Time saved for inspecting the quality of installations | | | | | | |
| | | | **Total saving** | | | | | | |
| 2. Analyzing, sharing and reporting the quality | | Enhanced documentation and automation of the issues identification | a. Time saved on storing recorded data | | | | | | |
| | | | b. Time needed for generating and submitting daily reports | | | | | | |
| | | | c. Time saved to review past weeks issues | | | | | | |
| | | Improved information flow of the quality data | a. Time saved on meetings/communicating with the subcontractors and architects/engineers on check-list | | | | | | |
| | | | b. Time saved for sharing issues to the directly concerned projects members | | | | | | |
| | | | c. Costs saved that are generated from traveling from office to site and back | | | | | | |
| | | | d. Costs saved for sharing this data (printing, shipping, etc...) | | | | | | |
| 3. Field issue solving | | Fast resolution of the issues | Time saved for issues to be resolved | | | | | | |
| | | | Reduction of unnecessary RFI's with the designer | | | | | | |
| | | | Costs/Reworks avoided saved to the quick issue resolution/ | | | | | | |
| | | | **Total saving** | | | | | | |
| 4. Enhanced Communication with the client | | Real-time update and root-cause of the issues to the client | a. Time saved on walking around site/meetings with the owner's inspector | | | | | | |
| | | | b. Costs saved for sharing this data (printing, shipping, etc...) | | | | | | |
| | | | c. Time saved on recording issues generated from the client | | | | | | |
| | | | d.Avoided costs from unnecessary work to identify the root-cause of the issue | | | | | | |
| | | | e. Avoided costs deriving from claims | | | | | | |
| | | | **Total saving** | | | | | | |

## C. Logistics & Safety monitoring

| Main applications/uses | Methods/tools/software applications/process/workflow | Benefits | Metrics | Manhours | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | Role | Time saved (h/week) | Internal hourly rate (€/h) | Number of people (n) | Duration (week) | Material savings (€) |
| 1. On-site safety monitoring | | Reduction of workplace injuries | a. Lost time of the workers because of injuries | | | | | | |
| | | | b. Time of absence of the injured worker | | | | | | |
| | | | c. Cost of the accident root cause analysis (the person who is going to prove that it was not the company's fault) | | | | | | |
| | | | d. Cost of damages | | | | | | |
| | | | e. Cost of damages caused to and/or replacement of equipment | | | | | | |
| | | | f. Cost of staff hired for replacing the injured personnel on absence | | | | | | |
| | | | g. Cost of lawsuits, fines, compesations and increased insurance rates | | | | | | |
| | | | **Total saving** | | | | | | |
| | | | | | | | | | |
| 2. Managing logistics and materials on the field | | Improved tracking of project Materials & Equipment | a. Costs saved on fuel by unnecessary movements of vehicles | | | | | | |
| | | | b. Costs saved of overordering materials required for an element | | | | | | |
| | | | c. Time saved on contacting suppliers to verify quantities and dilivery of materials | | | | | | |
| | | | d. Time saved for disposing/storing unnecessary materials | | | | | | |
| | | | e. Costs saved for disposing/storing unnecessary materials | | | | | | |
| | | | f.Reduction in time for inspecting and identifying materials and equipment | | | | | | |
| | | | k.Reduction in costs for recovery of stolen material | | | | | | |
| | | | g. Reduction in idle hours due to malfunctioning equipment | | | | | | |
| | | | h. Making possible to identify the materials for earlier starts and completions of certain tasks, reducing the project schedule (if the task is in the CP) | | | | | | |
| | | | i. Better selling out price of equipment since it has all the maintenance information stored | | | | | | |
| | | | j. Time lost due to late materials delivery | | | | | | |
| | | | **Total saving** | | | | | | |
| | | | | | | | | | |

# Appendix C. Interview Questions

### *General Questions (Probably for BIM managers, project managers, planners, designers)*

**1. What is your role in the project?**

**2. How do you define "digital construction"?**

**3. Do you work with digital construction tools in your daily tasks?**

**4. What was the status of the model during the preconstruction? What model, what LOD? Was an integrated model or it had to be modified by the site-office for constructability reasons?**

**5. Did you apply digital tools/processes in pre-construction phase for planning, estimating, clash detection and site-coordination & logistics, setting up checklists?**

**6. What and how do you receive design information (drawings, 3D models)?**

**7. If the model changes during construction how you handle it?**

### *Main Questions*

*Use & Benefits (Probably for site-engineers, superintendents, workers*)

**1. What benefits did you perceive while using mobile DC tools on-site activities?**

(Comparing with the traditional paper-based method)

**2. What is your process/workflow for keeping track of the activities and update the schedule?**

• Do you employ any site DC tools on the task?

• If yes, can you please identify benefits that derived from this use? (Please advise to my suggested Benefit List)

• If not, could you think of occasions that having used DC tools could help avoid certain costly events in the project? How could BIM/DC site tools add value on these missed opportunities?

**3. What is your current process/workflow for checking the quality of installations? (QA/QC checklists, identifying & resolving issues)**

• Do you employ any site DC tools on the task?

• If yes, can you please identify benefits that derived from this use? (Please advise to my suggested Benefit List)

• If not, could you think of occasions that having used DC tools could help avoid certain costly events in the project? How could BIM/DC site tools add value on these missed opportunities?

**4. What is your current process/workflow for coordinating the site? (Material & Equipment on-site tracking, Securing on-site safety)**

• Do you employ any site DC tools on the task?

• If yes, can you please identify benefits that derived from this use? (Please advise to my suggested Benefit List)

• If not, could you think of occasions that having used DC tools could help avoid certain costly events in the project? How could BIM/DC site tools add value on these missed opportunities?

*Implementation Barriers & Potential solution to overcome them*

**1. What problems do you encounter while using mobile DC tools on-site?**

**2. What are the reasons that you do not use mobile DC tools on-site?**

**3. What are the requirements for using these tools on-site?**

**4. What needs to be changed/ what would you recommend in order for people to use digital tools on site?**

**5. What is the most appropriate stage for the solution you have just mentioned?**

**6. Where do you think the biggest opportunities exist for technology to improve the way that construction projects are delivered?**

# Appendix D. Driving the standardization of site management processes

At this point, the author will analyze the ***best practices*** from the BAM's projects. This appendix should be considered as a first partial implementation of the standardization model developed in the figure 18. Sharing the best practices of the case-study projects can be considered as a first step for establishing a companywide standard site management approach. The three site management processes that were investigated are the progress tracking, quality control and material & equipment tracking. The elaboration of these processes will follow the same structure. At first the traditional way will be stated, followed by how BAM is enhancing this process with digital tools. Thereafter, the requirements and the benefits of this digitization will be discussed. Consequently, future recommendations for each process are included, in order to make the processes more effective and more possible to be standardized across the group.

## A. Quality Control (Identifying and resolving field issues)

***Traditional Process Vs Digital Process***

The traditional way of quality control entails a vast amount of paperwork and effort from the point of project team. Typically, when an issue is identified in the field, the site engineer should return back in his office find the appropriate QA/QC checklist that refers to the issue and then go back to the site to mark up his paper drawing and fill in the checklists. Thereafter, he is taking a picture on his phone, before returning back to the office and fill in spreadsheets as well as sending multiple emails to all the interested parties and subcontractors. On the contrary, digitizing this process is giving the user to simply create an issue by bringing up an issue template on his tablet. Attaching a photo to the issue is also automated, saving substantial amounts of time in the process. Once an issue is communicated to the subcontractor, they can automatically communicate their resolution back to the general contractor or client.

The following flowchart diagram is visualizing in high detail the traditional process of identifying, notifying and resolving issues against the digital process:

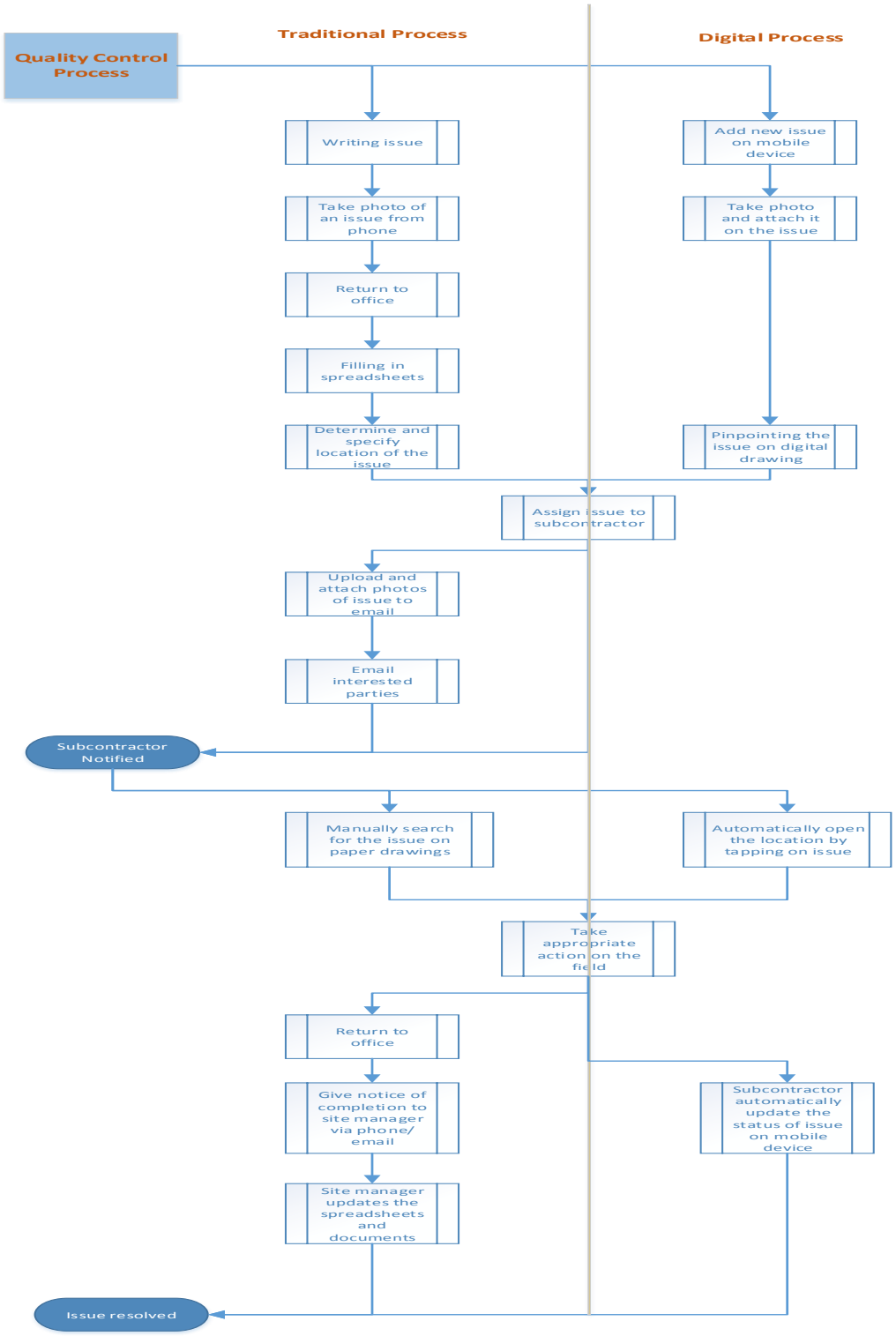


*Figure 19-Flowchart of quality control process (Traditional vs Digital)*

***Requirements***

Regarding the digital quality control process the requirements are minimum. Regardless of the size or type of a project, BAM can only benefit from this application.

***Benefits***

According to the interviewees, the benefits (apart from the general benefits that have been elaborated in chapter 4.1) of the digital quality control process:

- Reduction in time for identifying and notifying an issue
- Easy accessibility of the issues and their causes by every member at any time
- The information stored in a central repository can be searchable and retrievable years after the completion of the project
- Risk mitigation

In the following table, the calculations of the benefits in Oldbury project are presented. The project fully adopted a digital process for the quality control process and provided the author of a solid proof. The specific calculations are depicted in appendix D.

Table 13-Cost Savings (Oldbury project)

| Benefit Source | Calculations | Value |
|---|---|---|
| Time | Time saved multiplied by the rate/h | + £1,023,412 |
| Cost | Cost of gas | +£9,431.62 |
| | Printing costs | + £14,052.33 |
| Investment | Monthly payment iPads | - £37,827.14 |
| | License fee iPads | - £2,871.43 |
| **Total Cost Savings** | | 1,006,196£ |
| **ROI (%)** | | 2,472% |

***Recommendations***

The digital quality control process is not perfect yet. There is a series of action that the company should make in order to reach a possible standardization level:

- ***Create a standard filling system*** for all the QA forms, making the information available to everyone who is a part of the company.

- ***Selecting appropriate checklists***: Currently, there is a huge amount of generic checklists for almost every conceivable type of construction. Hence, it becomes extremely difficult for the system to adopt. The administration and site time required is extremely vast and proves to be too much of a burden to be able to actually do it effectively. Reducing the number of checklists would give the chance to the company to focus only on the important aspects that will cause severe rework and costs to be repaired and must not be overlooked. Carrying out a sort of risk assessment review of a project from a quality perspective will bring to the surface only the most vulnerable parts of that projects that are going to bear the biggest risk from a quality point of view. In that way, the checklists will become more meaningful and valuable, decreasing in number at the same time.

- ***Connecting the site tool with the 3D Model:*** Identifying an issue is currently being done on a 2D PDF drawing. This requires a lot of effort in the initial set up, as the project team should link all the PDF drawings with the 3D model, prior to the beginning of construction. Moreover, problems appear when the site engineer has to pin point an issue that maybe is not easily visible from a 2D drawing. Inserting the 3D model point of view on the site tool and the ability to navigate and pinpoint, will give the ability for pinpointing all the difficult areas of the project.

- ***Cloud web-based system:*** In the current BAM's quality control system (BIM Field360), the data are automatically updated (given there is an internet connection) and stored into the software. The software itself is not designed to use cloud data, maintaining enough free space on the mobile devices.

- ***Same quality inspection forms and templates across group:*** The QA/QC checklists should be identical/similar across the group, with the only difference the language.

### B. Progress control (Tracking progress of activities)

***Traditional process Vs Digital process***

Poor planning is a major source of inefficiency, waste, delays and poor decision-making; negatively impact a project's timeline and budget. As stated by the planner of Oldbury project, "if we have to do 13 things during the day, planning will be the 13$^{th}$". Companies need to improve the planning at the coal face and not only to satisfy the contract. Therefore, a digitization of the on-site progress tracking might have a big impact. The typical process for updating and monitoring progress involves the planners as well as the site engineers. Planners on site currently carry out regular progress reviews, typically based on the project's master or construction programme. Traditionally this is being done by walking around the site, observing progress achieved and talking to people to identify, by attending lengthy meetings or verbal informal discussions, how tasks are progressing. During this process the planner may take notes by manually handwriting them into a piece of paper or the hardcopy of the schedule. Progress photos are also taken, using a camera or their own mobile device. Thereafter, the planner will then return to the site office, manually input progress with the schedule software and store the photos. From the site engineer's planning perspective, the planner usually breaks down the construction programme into different sections. For every of these sections, the responsible engineer will take the programme and break it down into a more detailed schedule. Traditionally, the site engineers will fill in the site diaries either on paper or tablet while they are on site, and then return to the office to fill in the Excel spreadsheets in order to share information with the planner and client. The digital process is used by the site engineers to make the life of the planner easier. The site software tools for tracking progress, allow the users to automatically update their section mini-schedules and feed back to the master schedule (planner) in a streamlined and live manner. Moreover, the ability to create analytics via automated dashboards enables individual users, project teams, divisions and companies to better understand their dynamics of their work to promote efficiency. However, is not just the site team feeding information into planner, it is also needed for the planner to go out on site to verify that the activities are within schedule.

The following flowchart diagram is visualizing in high detail the traditional process of tracking the progress of construction activities against the digital process:

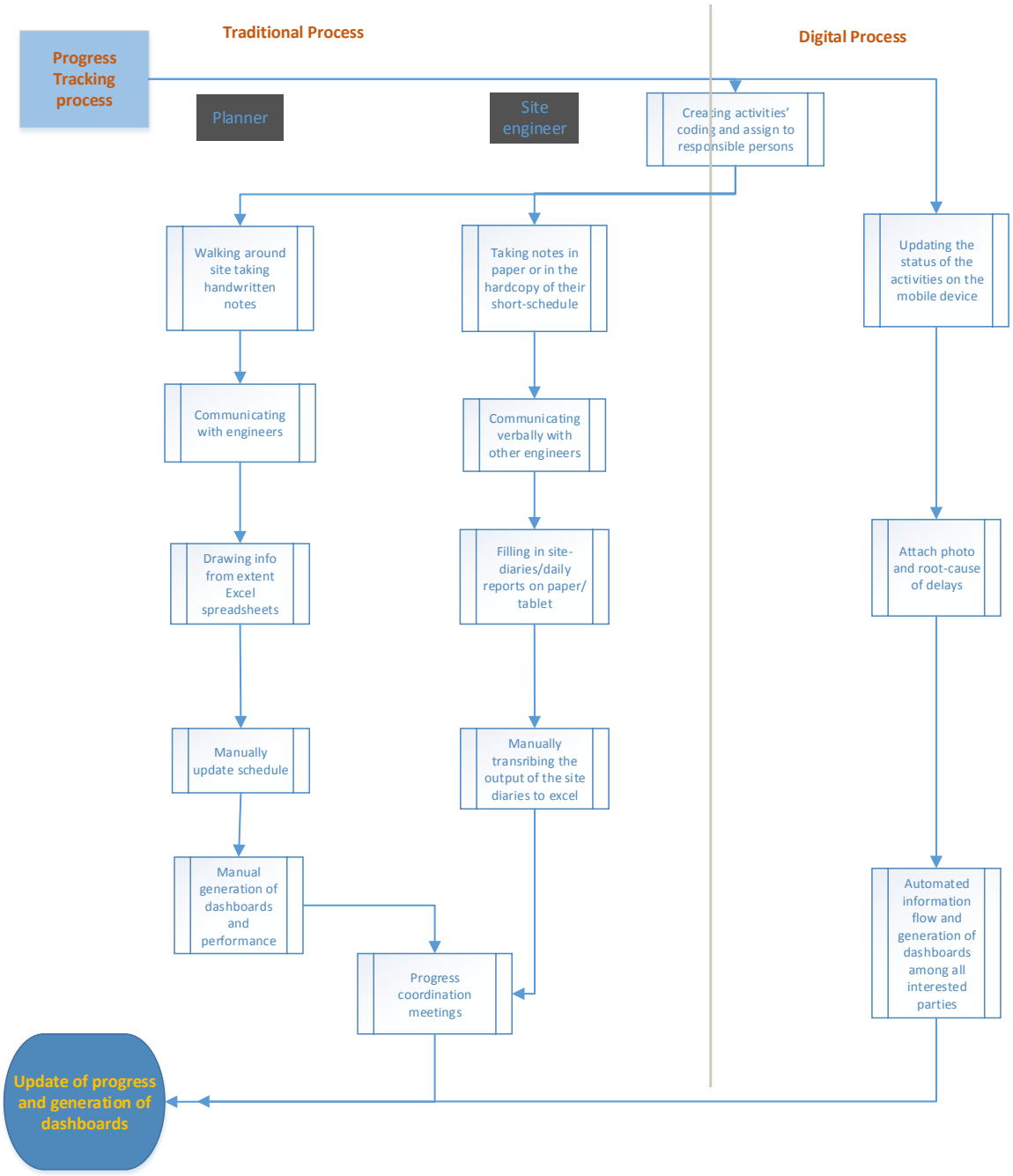


*Figure 20-Flowchart of progress tracking process (Traditional vs Digital)*

***Requirements***

There are certain requirements that the company should first take into account before selecting and deploying this digital process and the related software tools:

- Large site with multiple planners working to the same master schedule, so each planner can assign themselves their areas of the programme and as they update it, it becomes available to other planners. This means that time will be saved would be multiplied across all planners and better collaboration could be achieved.
- Large site with multiple section engineers but only one planner. Every section engineer can update his own short term plan and also share this information live to other section engineers. Enabling the identification of potential clashes with other users/subcontractors and save valuable engineering time.
- Single planner working across multiple projects. Via this digital process, the planner could assign projects to specific site/project managers to report on progress. When the site manager does the progress update, it shows up on the master schedule without the planner needing to go to site that often. This will save substantially travel time as well as giving the planner the extra time to focus on other projects that require more attention.
- Selecting a site software tool that is compatible with the software of the master schedule. It is important that the site tool selected, not only can acquire the information but can also be linked and automatically update the master schedule. In different scenario, the efficiency gains will be limited and so the difference from the traditional method.

***Benefits***

This process could bring benefits to the site engineers as well as the planners. In the BAM projects the following benefits were identified:

- Reduces site engineers time compared to the previous Excel method
- Improves understanding of the forthcoming works
- Identifies potential clashes with other users
- Adding notes/photographs making tasks visible
- Identifying the root-cause of delays
- Speeding up the reporting process by removing the need of re-keying of updates
- Enhanced control of which user (planner/site manager) updates what activities list
- Live and automatic dashboarding, saving time and providing better history records
- Reducing time spent on communicating and progress meetings

***Recommendations***

- One of the main barriers to the adoption of this process is the unwillingness of the site engineers to use an additional software. For the site engineer, is a duplication of work, as he also has to come back to the office early to fill-in his site diaries as well. In general, site diaries could become obsolete as the software tools are developing. The site diary should automatically have linked with an activity, linked also to a dashboard in order to be able to understand the progress straight away. Creating company's own application and template for the site diaries, through the adoption of Microsoft "power-apps". The output from these apps can directly be linked with the Power BI software, for the generation of dashboards. Another solution to that, is the BIM Field 360 that is currently used within BAM, providing more flexibility to the creation of the templates and site diaries. In order to reflect to what needs to be tracked in terms of progress and also be directly to an activity.

- Moreover, for overcoming the interoperability issues with the different planning software, there are certain recommendations that the company could take into account. Choosing a site application that has open API's with the planning software. Within BAM, the most prevalent planning software tools are *Primavera P6* and *Asta Powerproject*, therefore the selection of the *Oracle's "team-members"* and *the Asta Site progress mobile app*, respectively, is highly recommended.

- A future suggestion to the company will be the deployment of 4D planning and the site tool to automatically update the 4D model. However, the maturity of the company is not currently at this level and deploying a software tool, like *Synchro-site,* for keeping track of the progress would probably bring negative results to the team's efficiency. As the understanding of 4D planning increases within the company and especially among the planners, the use of a 4D site tool will become feasible and beneficial. The first attempts of utilizing the 4D model for progress tracking have already been implemented in some BAM's projects with the use of camera that is taking snapshots of the site and the comparison of the 4D model, in order to allocate whether certain activities are ahead or behind schedule.

## C. Material & Equipment tracking

***Traditional Vs Digital process***

Traditionally, the material and equipment are being monitored through paper forms and templates. Hence, the tracking and updating of the lists of equipment and material is manual and requires that the engineer has to come back to the office to this update. By linking the mobile tools with the use of electronic identification (RFID, QR codes) that are linked to every piece of material and equipment, it becomes possible to coordinate and keep track of the site at any time. The RFID tags/barcodes that are placed on every component, can be scanned with handheld computers providing all the corresponding details (status, checklists, etc) in the linked BIM software. Furthermore, the materials and construction equipment such as cranes, bulldozers can also be scanned through these systems. In particular, this technology can give all the necessary information to the site supervisors and construction managers ensuring an accurate inspection and verification of the materials and equipment. From all the projects the author visited in the UK, only one project has turned the inspection of the equipment into a digital format. Linking the inspections of plant equipment with the BIM model, through the use of BIM Field 360, the project has acquired important benefits, intangible & tangible, that will be presented below.

***Benefits***

This process could bring benefits to the site engineers as well as the planners. In the BAM projects the following benefits were identified:

- Reduces site engineers time compared to the previous Excel method
- Improves understanding of the forthcoming works
- Identifies potential clashes with other users
- Adding notes/photographs to certain tasks
- Identifying the root-cause of delays
- Speeding up the reporting process by removing the need of re-keying of updates
- Enhanced control of which user (planner/site manager) updates what activities list
- Live and automatic dashboarding, saving time and providing better history records
- Reducing time spent on communicating and progress meetings

Moreover, specific calculations were carried out by the project team of Thames Tideway, to support the initial investment. The detailed calculations are presented on the appendix E.

Table 14-Return on Investment-Plant Equipment tracking

| Benefit Source | Calculations | Value |
|---|---|---|
| Time | Time saved multiplied by the rate/h | + £895,874 |
| Investment | Supply and installation of software | - £4,200.00 |
| | Set up cost for all sections | - £3,474.00 |
| **Total Cost Savings** | | **888,200.00£** |
| **ROI (%)** | | **11500%** |

***Recommendations***

- Involvement of the supply chain in this digital process. The project team of "Thames Tideway project" spent a considerable amount of time on barcoding all the plant equipment on the construction site, prior to the implementation of the system. What can be recommended is that the company's suppliers have already inserted a unique barcode to each of the equipment arriving on site.
- Inserting RFID tags/Barcodes on materials. According to the interviewees, mainly project managers, material tracking could provide huge benefits for tracking the material location, status and purpose. There were massive costs and delays due to the late delivery of materials. Also, using mobile devices to record accurate material data in the field can then be used successfully for the FM setup. Unfortunately, the project managers were unable to put a price on those missed opportunities.

## Appendix E. Cost Savings Calculation-Oldbury project (Table 15)

| Benefit Source | Calculations | Value |
|---|---|---|
| Time | Reduced number of trips for staff returning to office for information from average round trip from Kelvin Way to J1 [17mins - (0.6miles)], travel through site at 11mph [12mins - (1.99miles)] and then from J2 back to Kelvin Way [14mins - (1.8miles)] = **43mins per trip**.<br><br>This equates to 101 iPad users saving one trip per day which is 28,162 hours saved travelling.<br><br>BAM engineering staff= £36.34 per hour - average based on Engineering Staff Rate Card.<br><br>Hours saved multiplied by the rate per hour | <br><br>28,162 hours<br><br>£36.34 per hour<br><br>+ £1,023,412 |
| Cost | Materials Costs Saved:<br>Fuel [diesel] costs per return trip = £0.48<br>Cost of Diesel per return trip x No of Users x number of days [based on one trip per day per iPad user] = **£18,862.08**<br><br>Deduct 50% fuel to encourage car sharing<br><br>Paper & Printing Saved per TQ/Design Change = **£14,052** | <br><br><br><br>+ £9,431<br><br>+ £14,052 |
| | | |
| Investment | Investment of iPad Licenses and monthly hire charges for technology and equipment to Deduct<br><br>Monthly charge x No of iPads per month **= £37,827.14**<br>License fee/set Up charges based on 101 iPads = **£2,871.43** | <br><br><br>**-** £40,699 |
| Total Cost Savings (£) | | £ 1,006,196 |

## Appendix F. Cost Savings Calculation-Thames Tideway project (Table 16)

| Benefit Source | Calculations | Value |
|---|---|---|
| **Time Saved** | PPM Coordinator: @ £17.00 per hour<br><br>PPM Coordinator will spend 5 hours per day recording info on a site in a note book. Based on 46 weeks per year. (52 weeks less 6 weeks' hols/shutdowns etc.)<br>Then he will spend 5 hours transferring info onto worksheets on PC.<br>Using/inputting straight onto BIM. | Saving:<br>**£19,550.00p/year**<br><br>**Over 4-year period a saving of £78,200.00p** |
| | Fitter on site @ £23.50 per hour<br><br>A service takes on average 6 hours. Recording/inputting/filing results might take an extra 1.5 hours.<br>So @ 1.5 hours 7 times a week - would equate to £176.25 per week.<br>46 weeks would equate to £8107.50p<br><br>7 fitters on average do 1 plant service every day. (based on shift x 3 per day). | Savings: 7 x £8,107.5pp = £56,749.00p x 3<br>**=£170,367.00p/year**<br><br>**Over a 4-year period £681,468.00p.** |
| **Investment** | Cost of BIM to Project. | One off payment of **£4,200.00p** supply and installation of software. |
| | Training and support - £45.00 per hour<br>Development of bespoke equipment template £65.00 per hour<br>Asset upload onto system - £45.0 per hour<br><br>3 x I pads per section £1078.00p<br>1x printer for barcode per section £80.00p | Set up cost per section would be **£1158.00p**<br><br>**For 3 sections: £3.474,00** |