Towards an automated photogrammetry-based approach for monitoring and controlling construction site activities

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Abstract

The construction industry has a poor productivity record, which is predominantly ascribed to the ineffective approaches for early detection of delays. Most available approaches do not offer key stakeholders a shared understanding of project performance in real-time, which as a result failed to identify any project slippage on the original schedule. This study reports on the development of a novel automated system for instant detection of delays through automated construction progress monitoring and updating of status in real-time. The proposed system seeks to harness advances in close-range photogrammetry, BIM and computer vision to deliver an original approach that is capable of continuous monitoring of construction activities, with the aim of progress status determinable, at any given time, throughout the construction stage.

The research adopted a sequential mixed approach strategy pursuant to the design science standard processes in three stages. The first stage involved interviews within a focus group setting with seven carefully selected construction professionals. Their answers were analysed and provided "*the informed-basis for the development of the* automated *system"* for detecting and notifying delays in construction projects. The second stage involved development of ‘proof of the concept’ in a pilot project case study with nine potential users of the proposed automated system. Face-to-face interviews were conducted to evaluate and verify the effectiveness of the developed prototype, which as a result was continuously refined and improved according to the users’ comments and feedbacks. Within this stage the *prototype to was tested and evaluated by a representative of construction professionals*. Subsequently a sub-stage of the system’s development sought to test and validate the final version of the system in the context of a real-life construction project in Dubai whereby an online survey is administered to 40 users, a representative sample of potential system users. The third stage addressed the conclusion, limitations and recommendations for further research studies for the proposed system.

The findings of the study revealed the feasibility of implementing a system that fully automates schedule progress monitoring, with no manual intervention for the following elements of a power station’s civil works: raft foundation, beams, slabs, walls and columns. This was achieved through fully automated photogrammetric data collection, interpretations and analysis with the aid of computer vision and image processing algorithms as well as BIM. Consequently, human errors and subjectivity are eliminated, and accordingly the trialed system achieved a significantly high level of accuracy, automation and reliability on the live construction project used as case study in this research. An accuracy of 99.98% was recorded for raft foundation, beams and slabs and for walls 99.97%, whereas 99.70% accuracy achieved for columns, with the system's overall accuracy being 99.85%. Moreover, the findings also highlighted the feasibility of a low-cost approach for automated construction progress monitoring through combination of tools for image capture, processing and modelling. Based on comparative analysis, the proposed system assisted site teams to complete the case study project 61 days ahead of its planned schedule with a 9% time saving and 3% cost saving after a sixteen months case study trial on a live power station project. In addition to the high levels of accuracy, the developed system represents a step change in the way construction delays are detected and provides a pathway for integrating BIM, photogrammetry and computer vision for project management.

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List of Abbreviations

AED	United Arab Emirates Dirham
AI	Artificial Intelligence
AOV	Angle Of View
AMAC	Automated Monitoring And Controlling system
BIM	Building Information Modeling
CV	Compute Vision
DEWA	Dubai Electricity and Water Authority
EVM	Earned Value Management
DOF	Depth Of Field
FOV	Field Of View
GIS	Geographic Information Systems
GSD	Ground Sampling Distance
HD	High Definition
Kv	Kilovolt
LADAR	Laser Distance And Ranging
LIDAR	Light Detection and Ranging
LS	Laser Scanning
ML	Machine Learining
PDA	Personal Digital Assistants
PM	Project Manager
PTZ	Pan, Tilt, Zoom
RC	Reinforced Concrete
SMS	Short Message service
UAE	United Arab Emirates
UK	United Kingdom
UPS	Uninterruptible Power Supply
VR	Virtual Reality

Dedication

Although my Mother passed away 37 years ago, she is still my source of inspiration, to my Mother, Hamdeen Al-Gendy.

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My endless praise and thanks to Allah, for giving me the patience and power to successfully complete my PhD study.

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Chapter 1-Introduction

1.0 Background

1.1 Project overruns and their implications on the construction industry

Despite the utmost importance of the construction industry, for decades poor performance has been and continues to be a challenge for the construction industry globally. Indeed, the punctual delivery of projects is one of the most predominant key indicators for judging successful performance of construction projects (Narayanan *et al*., 2019).

Several researchers have investigated the adverse implications of time delays on construction projects which commonly result in poor performance (Narayanan *et al.,* 2019), poor productivity rates (Nojedehi and Nasirzadeh, 2017), low profit due to cost overrun (Kim *et al.,* 2008), late delivery of projects and time extensions (Senouci *et al.,* 2016) with several claims that result in contractual and personal tensions (Cheung and Pang, 2013), a bad reputation for the contractor (Aryal and Dahal, 2018), and the client on occasion losing the trust of his stakeholders and funding bodies (Mukuka *et al.,* 2015).

Mukuka *et al*., (2015) defined time delay as the difference between the planned/original delivery date and the actual delivery date in percentage terms. Similarly, cost overrun as defined by Merrow (2011) is the difference between the original contract value and the actual construction cost at the time of delivery as a percentage.

A global research study conducted by Adam *et al.,* (2016) examined a significant number of construction projects in 20 countries from 5 continents for both developing and developed countries from the late 1920s until the late 1990s. They concluded that the challenge of time delays is a persistent and pervasive problem worldwide.

In their research conducted for the UK's construction industry, Zidane and Andersen (2018) concluded that almost all medium and large size construction projects suffered from delays. Several researchers and industry professionals have stressed that, delay and cost overrun are conjoined, as time delays inevitably leads to cost overruns (Ramanathan *et al.,* 2012; Amusan *et al.,* 2018; Afzal and Yunfei, 2019). Instinctively, once a new project is announced in the media, it is commonly assumed that it will be completed beyond its planned delivery date and will exceed its original budget (Morris, 1990; Raftery, 2003; Siemiatycki, 2009; Adam *et al.,* 2016).

Fouracre *et al.,* (1990) conducted a study for the UK Transport and Road Research Laboratory (TRRL) to investigate 15 metro projects constructed in developing countries that experienced time delays and cost overrun. They found two projects suffered between 100 to 500% cost overrun, six projects experienced 50%, three had 20-50% , and the remaining four ranged from 10 to 20% cost overrun. Similarly, Auditor General of Sweden (1994) studied 15 rail and road projects, and their findings revealed about eight road projects experienced 86% cost overrun, and seven rail projects recorded 14-74% cost overrun.

The literature study offers a staggering amount of evidence concerning the adverse repercussions of cost and time overrun for the construction industry worldwide. Odeck and Skjeseth (1995) studied construction projects in Norway and concluded that there was between 10% and 170% variation in delays and cost overrun amongst the studied projects. Eight years later, Odeck (2003) concluded that the construction industry in Norway did not record any improvement with projects suffering between 59% to 183% time delays and cost overrun. In Spain, Ganuza-Fernandez (1996) contended that 77% of the investigated construction projects delivered beyond their planned completion date and faced cost overrun, of which a third of those projects experienced 20% cost overrun. Likewise, in the Far East, Kaming *et al.*, (1997) established that, more than 92% of building projects in Indonesia suffered time delays and cost overrun. Whilst in Canada, WU (2006) studied 50 construction projects and reported that, all those projects suffered on average an 82% time delay and cost overrun. According to Baloi and Price (2003), more than 63% of mega projects funded by the World Bank exceeded their original budget due to incurred delays.

In 2008, Lee (2008) conducted a study of 161 construction projects in South Korea comprising of 138 road projects, 16 rail projects, 5 ports and 2 airports. Following a thorough investigation, he concluded delays incurred, resulted in 95% of road projects facing a 50% cost overrun, whereas all rail projects faced a 50% cost overrun, the five port projects encountered a 40% cost overrun and both airports experienced 100% cost overrun.

In India, Gupta (2009) studied 290 construction projects with an overall cost of ₹270.6 billion (£2.91 billion) and reported that the additional cost due to the unmanaged delays was ₹ 200 billion (£2.15 billion) and all projects met with an average cost overrun of 73%. Similarly, Zujo *et al.,* (2010) examined 92 construction projects in Slovenia, and found that all the examined projects faced more than 51% cost overrun. In the UK, the original contract value for Edinburgh Tram System was £320 million, and due to an ineffective system for delay detection, the project was delivered three years after its original contract completion date. At the time of delivery, the actual cost was £776 million, this vividly manifests the drastic cost overrun of 242.5%, mainly because of the inordinate time delays (City of Edinburgh Council, 2014).

According to Love *et al.,* (2013) time delays and cost overrun were found in construction projects without exception and as such regardless of project size, type or procurement methods utilised. In a broader study Chen *et al.,* (2015) investigated the performance of 418 Design & Build (DB) construction projects in the USA and they reported more than 90% of the projects were delivered beyond their contractual date, with more than 50% cost overrun.

1.2 State-of-the-art in approaches and tools for project delay detection

There has been a great deal of effort made to improve the monitoring and detecting of project delays in the construction industry. These approaches can be classified into three categories, as follows:

1. Manual approach, which is the most widely used and dominating within construction projects and does not utilise any technology, specifically during data collection (Golparvar-Fard *et al.,* 2009; Kimoto *et al.,* 2005; Yang *et al.,* 2015).
2. Standalone system, in which only one technology is utilised in addition to the manual approach (Retik and Shapira, 1999; Abeid *et al.,* 2003; Chau *et al.,* 2004).
3. Integrated system, wherein more than one technology is integrated to automate the processes of delay detection (Golparvar-Fard *et al.,* 2009; Behnam *et al.,* 2016; Braun and Borrmann, 2019).

1.2.1 Manual approach for monitoring construction progress that enables delays detection

Whilst, technological advancements have enabled even manual processes to be more accurate and efficient, essentially the manual approach is based on a paper method for data collection and recording. This traditional approach is laborious and extremely slow as it requires a large number of inspectors to collect the data visually from the site, recording their observations on paper and finally organising and analysing the data at the site office (Kim *et al.,* 2008; Golparvar-Fard *et al.,* 2011; Solihin and Eastman, 2015).

This manual-based site monitoring and updating system has several limitations, such as missing, incomplete or incorrect information. Consequently, Project Managers (PM) commonly fail to obtain reliable progress data. This approach tends to lead to confusion, often resulting in PMs misjudging the actual progress of their projects. Subsequently, flawed decisions are made, which has severe consequences of the effectiveness of the use of resources. For example, Kim *et al.,* (2008) reported that based on the manual progress monitoring system, a PM judged an activity to be only 30% finished, while in reality, it was 60% completed. In this case, the PM believed that the construction project was delayed, even though it was proceeding ahead of the planned schedule. Consequently, the PM deployed more resources than needed to that activity, which resulted in a waste of time and money. This demonstrates that, this manual approach for monitoring the delays in construction projects are unreliable, inaccurate, time consuming, laborious, costly and prone to errors and subjectivity (Navon and Sacks, 2007; Turkan *et al.,* 2012).

1.2.2 Standalone systems for detecting delays through monitoring construction progress

In the standalone system only one technology is utilised (Navon, 2000). Earlier efforts by Navon (2000) focused on the development of a robotic system that could not only install tiles, but additionally monitor the site as it was equipped with cameras to measure the progress of the installed tiles. However, the robotic system required continuous human intervention for stabilisation and system calibration. Moreover, the robot was monochromatic, which in poor lighting conditions, especially indoors, affected adversely the accuracy of progress measurements. Therefore, the proposed robotic system lacked accuracy and reliability. It is worth mentioning that Navon (2000) himself considered the system incomplete and required further developments to minimise or eliminate human intervention.

A more developed automated system proposed by Dick *et al.,* (2004), produced an automatic framework acquisition for the 3D as-built model. The model was constructed from a small number of site photos by developing an algorithm that enabled recognition of the structural objects from the site photos. This framework succeeded to a limited extent in comparing the as-built 3D model against the as-planned one. However, the results lacked the sufficient accuracy for site monitoring, as the optimal accuracy was 83% for vertical elements and 91% for horizontals.

A further advanced system proposed by Lukins and Trucco (2007) used Computer Vision (CV) to develop a classifier that can observe and detect changes (the progress status) during construction through a fixed camera. This was achieved by developing the prior building model and aligning it with the camera scenes to identify the progress. However, the system suffered from several limitations, including weather interference, occlusions, and daylight fluctuations. In addition, the whole system required continuous manual intervention for operation. Consequently, the accuracy of the classifier is subject to the operator’s precision and as a result makes the system prone to errors and is also time-consuming.

Evidently the standalone systems proposed for monitoring the delays in construction projects failed to accomplish their objectives, as they are unreliable, inaccurate, time consuming, and prone to errors and subjectivity (Ibrahim *et al.,* 2009; Roh *et al.,* 2011; Gloparvar-Fard *et al.,* 2011).

1.2.3 Integrated systems for detecting delays through monitoring construction progress

The impetus of recent efforts shifted attention to mixed technologies to address the limitations of stand-alone technology. Software developers such as Autodesk were motivated by trying to overcome the recognised limitations pertaining to conventional monitoring systems. Autodesk developed a semi-automatic cloud-based system to collect data from construction sites using Personal Digital Assistants (PDA) such as tablets or smartphones. Largely, PDAs overcame some of the recognised limitations, specifically those related to the time required to collect data (Kimoto et al., 2005; Kim et al., 2008). However, Autodesk's software system still relied heavily on inspectors to manually insert the construction site updates, which were not only subjective but also unreliable. Consequently, this method lacked the instant detection of delays, reliability and accuracy.

Accordingly, El-Omari and Moselhi (2011) proposed the integration between Laser Scanning (LS) and photogrammetry to enhance the speed and accuracy of the acquired data from construction sites. This system succeeded in building a 3D as-built point cloud model with satisfactory accuracy from integrating LS and photogrammetry techniques and synchronising the common points between the two-point cloud models. Using the constructed 3D point cloud model, a comparison could be seen between the progress (as-built) model and the as-planned model. One of the main limitations of this system is the time required to perform a single scan. Indeed, to scan the entire built asset, multiple moves are required from different positions, which makes this system time-consuming and cumbersome. In addition, specialised technicians are often needed to perform the scans to collect accurate data. Above all, the LS technique is still relatively expensive, which impedes its applicability for the required regular updates of construction site activities, to support timely and informed management decisions.

A similar system proposed by Ibrahim *et al.,* (2009) relied on CV techniques to develop a progress monitoring system. This system analysed the geometric and material properties of the components in a BIM model and compared it with the corresponding elements from the collected site photos (the as-built). The comparison helped to identify the changes, reflected in the progress status of the construction site, which was then used to update the Work Breakdown Structure (WBS). Despite the promising results, the system suffered from several limitations, including a lack of sufficient detail of the elements in the collected photos, which in turn negatively affected the synchronisation with the BIM elements. Consequently, several elements could not be recognised, which had an impact on the accuracy and reliability of the collected data.

Another integrated system developed by Golparvar-Fard *et al.,* (2009) sought to automate monitoring the construction site activities by combining photogrammetry and time-lapse techniques to superimpose the as-built point cloud model constructed from the site photos over the as-planned 3D model, using the Augmented Reality (AR) technique. This system was able to depict the progress status using colour codes, where green referred to 'on-schedule,' dark green as 'ahead of schedule,' and red as 'behind schedule.' However, this monitoring system suffered from a mismatched level of detail in the baseline schedule (as-planned), compared with the actual site. The proposed system could only recognise the completed activities with the same patterns, and overlooked incomplete/on-going activities. In addition, manual intervention was needed to filter and select the suitable photos, which made the process time-consuming, and highly dependent on the operator's experience and visual ability. Moreover, replicating the construction progress in a colour coding system was also deemed unsuitable for staff suffering from colour-blindness.

Two years later, Golparvar-Fard *et al.,* (2011) further developed previous research that evaluated the status of construction progress using the same approach as the colour-coding system. In contrast this method used colour codes to represent time and cost values, as an analysis for Earned Value (EV). However, this later study did not address the other limitations of the Golparvar-Fard *et al.,* (2009) proposal.

Another system, proposed by Roh *et al.,* (2011), endeavoured to resolve some of the flaws in previous systems by comparing the components of the as-built, abstracted from site photographs, against the as-planned BIM model. This was achieved by developing a classifier algorithm to synchronise the objects from BIM models with corresponding objects from captured photos. This system succeeded in illustrating the progress of construction components in percentages. However, due to significant manual intervention required with critical data such as location and time being manually inputted, it made the system unreliable and inaccurate. Furthermore, training the classifier was an extremely time-consuming process, whereby the development of the algorithm required manual synchronisation of the construction elements, and thus, the classifier's accuracy heavily depended on human accuracy.

More recently, Dimitrov and Golparvar-Fard (2014) developed an algorithm that used a material texture recognition technique to automatically create 3D models by extracting the information from randomly collected site photos of construction elements (columns, walls, slabs, etc.). These automatically created 3D models were further used to depict the construction progress, after comparing them with the as-planned schedules. The proposed system was distinguished by its simplicity, but also challenged for its inconsistent accuracy that affected reliability. The system's accuracy varied from one material to another: with the accuracy for the material recognition algorithm being 92.1% for casted concrete, and 92.3% for compacted soil. High accuracy of 100% was achieved in three elements only (formwork, grass and marble), but these elements are considered minor elements in the construction industry (i.e. they usually have less impact on the critical path). In addition, the richness of the pre-prepared material recognition library greatly dictated the accuracy of the constructed 3D model. Therefore, some construction elements could not be recognised by the algorithm, leading to significant confusion from the constructed 3D model.

The latest research by Behnam *et al*., (2016) proposed an automated system to generate and visualise the progress status of the repetitive construction activities for linear infrastructure projects. They integrated satellite remote sensing techniques and a Geographic Information System (GIS) web-based platform to build 3D models from satellite images and locations recognised by the GIS system. The accuracy of the created 3D model was improved by the collected site photos. Further comparison between the 3D created model and the 4D BIM model depicts the progress status in the form of visualised charts for easy understanding by the PM and other stakeholders. The proposed automated system succeeded, to a certain extent, in addressing some of the limitations of the previous automation attempts to monitor the progress of construction site activities. However, this system cannot be used for all site activities, as it is limited to linear projects with repetitive activities, such as pipelines, road works, and railways. In addition, it did not provide sufficient information about start dates, which needed to be inserted manually. Therefore, the system was deemed not fully automated as manual intervention is required to conjugate the geographical objects between the collected site photos and satellite images. Consequently, even for the longitudinal projects, the accuracy and the reliability of progress updates are still questionable.

Ultimately, this review revealed that to-date there is no approach/system that has successfully automated monitoring, analysing and controlling construction site activities to detect instantly any delays in real time.

1.3 Gaps in knowledge

Increasingly, a number of systems developed have attempted to overcome the weaknesses of the manual approach by automating the processes of data acquisition and analysis for reporting the project status. These systems have aimed to monitor the construction progress by supporting decision makers with reliable information of the progress status to pinpoint the delays.

However, systems that have utilised technologies have faced similar limitations as the manual approach; wherein, one or more of its processes has heavily relied on the human involvement for taking actions or judging on processes or results. This manual intervention made these systems time consuming, prone to errors, inaccurate, unreliable, costly, lacking in instantaneous detection of delays and deemed semi-automated (Dainty *et al.,* 2006; Golparvar-Fard *et al.,* 2012; Turkan *et al.,* 2013; Maalek *et al.,* 2019). According to Shrestha *et al.,* (2013) and Love *et al.,* (2016), despite the adverse consequences of delays within the construction industry, there is currently no reliable resolution nor progression to overcome this impasse.

In summary, the current monitoring systems have several limitations that restrict their efficiency and reliability to determine the precise progress status. Consequently, these systems are not widely adopted as the construction practitioners are averse to utilising them, as these systems are costly, require significant training for use and additional specialists, and they are disruptive to the as-usual daily operations (Langlois, 1988; Jernigan, 2008). Accordingly, the identified weaknesses and limitations of the current systems and approaches could be used as a way to encourage construction professionals to adopt a new system. This proposed system should be fully automated to offer daily progress updates via automatic notifications, easy to use, cost effective, and should not be disruptive or overburden construction activities.

The research questions are derived from the literature study to address gaps in knowledge for this research area.

1.4 Research questions

The research seeks to answer the following questions:

1 How to monitor the construction progress in order to find delays?
2 What is the approach/system for monitoring the progress that enables instant detection of delays?
3 How to find out delays instantly through appropriate progress monitoring system?

1.5 RESEARCH AIM AND OBJECTIVES

The aim of this study is to develop an automated system for monitoring the progress of construction projects in order to enable automatic detection of project delays to inform timely decision-making. The proposed system will help decision-makers to obtain accurate information about detected delays, in a timely manner and will assist them to make the right decisions in order to address any potential project overruns.

Objectives:

To achieve the aim of this study the following objectives, will be pursued:

1. Critical review and identification of requirements and needs through a review of literature as well as state-of-the-art on automated progress monitoring systems.
2. Contextualise a hypothetical approach as an alternative and effective solution for automated construction progress monitoring.
3. Prototyping incrementally an automated system for construction progress monitoring by integrating photogrammetry, computer vision and Building Information Modelling (BIM).
4. Test the prototype system in practice to validate the novelty of the proposed approach for automating monitoring the progress in construction projects in order to detect the delays.
5. Evaluate the theorised approach of the system to develop recommendation for future research and practice.

1.6 Outline of research methodology

As the purpose of this research is to develop an automated system to address the detection of time overrun in the construction industry, this research adopted a sequential mixed approach strategy. This included a focus group, followed by two case studies, administered and directed by the standard processes of the design science approach. Design science is a widely used approach for construction management research which guides the researcher step-by-step according to its standard processes for the correct implementation of research to achieve research objectives. Thus, this study will be executed in 3 main stages as explained below:

Stage 1 - Pre-development (objective1)

- **Literature Review:** Extensive investigation to acquire deeper knowledge of existing literature to understand state-of-the-art current monitoring and updating systems with a special focus on limitations, advantages and the technology employed for each initiative. **The output** of the literature study is a "*synthesis*" for the literature review, which will be validated by a representative sample of users using a focus group approach.
- **Focus group (qualitative approach)**: the focus group will be conducted with seven carefully selected professionals who have practical experience of construction projects, combined with a robust in-depth knowledge of delays within construction. They will be asked open-ended questions to evaluate the features and components of the proposed system, derived from analysis of state-of-the-art for the developed approaches, tools and techniques in the detection and notification of project overrun. Participants' answers will be analysed using NVivo software. **The output** will provide *an informed basis for the development of an* automated *system* for detecting and notifying delays in construction projects.

Stage 2-I - Development of the prototype system (objectives 2 and 3)

This stage involves the development of the proposed automated system to detect delays and to provide automated notification for decision-makers. Participants of this stage will be nine users of the system representing a sample of contractors, consultants, and owners of the pilot project case study in Dubai. They will be asked open-ended questions via face-to-face interviews, to evaluate and verify the effectiveness of the developed prototype. The prototype will be continuously refined and improved according to the users' comments and feedbacks. **The output** will be "a *prototype that is tested and evaluated by a representative of construction professionals*".

Stage 2-II: Development (Validation of the final version of the developed system in a real-life construction site case study- quantitative approach) (Objective 4)

This stage aims to test and validate the final version of the developed system with 40 users of the system in the context of a real-life construction site in Dubai, United Arab Emirates. This validation allows a comprehensive comparison of the effectiveness of the developed system in comparison to conventional monitoring and notification approaches; the manual standalone and integrated systems found in the literature reviewed. An online survey using a Qualtrics platform will be administered to the representative sample of potential system users to assess the effectiveness of the system. The collected data from the 40 users (i.e. contractor, sub-contractor, consultant, and owner) will be statistically analysed using SPSS. **The output** will be the "*developed system for construction overrun identification and notification"*.

Stage 3- Post-development (Conclusion and recommednation) (objective 5)

This stage will address the conclusion, limitations and recommendations for further research studies for the proposed system.

1.7 Scope of research

The proposed system will be limited to civil works such as Reinforced Concrete (RC), elements (i.e. foundations, raft foundation, beams, slabs, walls, columns, brickworks, etc.) of an electric sub-station allocated in Dubai and owned by Dubai Electricity and Water Authority (DEWA). The system will be developed and verified in a pilot project case study and will then be validated in a full lifecycle case study. Both case studies are allocated in Dubai and owned by DEWA.

These case studies were selected, mainly due to the construction duration for the substation being relatively short (18 months), which makes it suitable to test the proposed system, within the timescale of this study. Moreover, the substation was carefully selected as DEWA had frozen the design of this type of substation over the last two decades.

Another key reason for conducting the research in Dubai for projects owned by DEWA is that, the researcher works as a Specialist (Head of the Technical Development unit) for DEWA. With 16 years working in Dubai within the construction industry, the researcher has a good network of relationships within the construction industry in Dubai, as well as access to real-life case studies that facilitate data collection. As such, the research is conducted on the project that the researcher is working on; accordingly, all participating stakeholders of the pilot project and case study are known to the researcher.

1.8 Significance of the research

Despite the major role that the construction industry plays as an important component and vital contributor for the sustainable growth of the global economy (Ruddock, 2009), its historical performance demonstrates persistent time delays and cost overruns, and accordingly this issue warrants prompt action.

Therefore, preventing time delays and cost overrun in construction projects is deemed as one of the most significant concerns for governments, researchers and industry professionals alike. To that end, there have been many endeavors intended to detect time delays early, utilising standalone and integrated technologies in addition to the conventional manual approach. Hitherto the reoccurring delays and cost overruns in the construction industry offer concrete evidence of the failure of these current systems to improve the performance of the construction industry.

Indeed, this research proposes a long overdue solution to respond to delays in construction projects, whereby, the proposed system sought instantaneous detection of the delays once they occurred. And accordingly, the system will send notifications automatically to the decision makers via email and SMS for their prompt attention and action. These instant notifications will enable construction staff to recover delays on a daily basis and therefore complete the construction project without delays or even ahead of its original completion date. The proposed system will ultimately contribute to exponential growth in the construction industry and consequently in the global economy.

1.9 Thesis organisation

This thesis is divided into nine chapters; the structure of each chapter is summarised as illustrated in **Figure 1.1**.

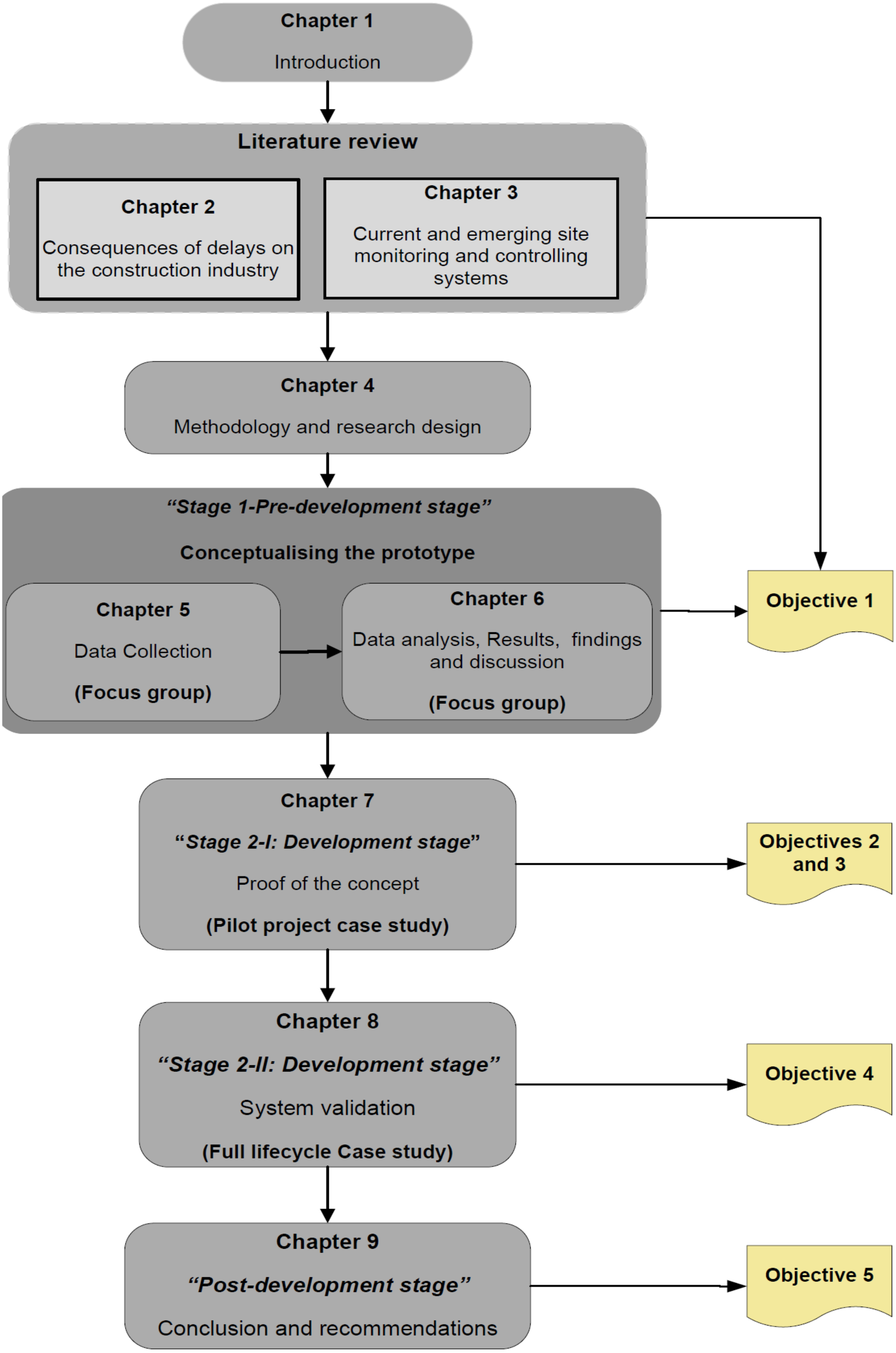


Figure 1.1: Thesis organisation

Chapter 1: Provides the rationale for this research topic, its timeliness and prevailing gaps to address the challenges for instant detection of delays in construction projects. It also provides the research aim and objectives followed by the methodology that the research will follow to collect and analyse the data. Finally, the scope and significance of the research are outlined in the last section of this chapter.

Chapter 2: Consists of the literature review which introduces the concept of delays in the construction industry including key definitions, statistics and their implications. It also includes detailed investigation of the root causes of delays in the construction industry worldwide, followed by the approaches that currently deal with construction project delays shedding more light on the traditional manual approach for monitoring and controlling delays in construction projects.

Chapter 3: Encompasses a review of literature concerning state-of-the art for current and emerging technologies which propose to monitor and control delays in construction projects and includes the benefits and limitations for each system. Each proposed system has used certain technology, which therefore requires an introduction to the technology as well as introducing the necessary definitions to the reader before investigating further the proposed systems.

Chapter 4: Introduction to research design and adopted methodology and justification for choosing the sequential exploratory mixed approach is explained. This approach opens with a focus group interview in the pre-development stage, followed by the development stage which involves interviews with the users of the developed prototype in the pilot project case study. And finally, the post-development stage which entails validation of the final version of the proposed system with system users undertaking online surveys.

Chapter 5 and 6: These chapters introduce the data collection, analysis and findings of the focus group interview at the pre-development stage followed by the findings of the qualitative data which are the foundation for the development of the prototype.

Chapter 7: this chapter introduces the development, testing and verification of the prototype for the proposed system in a pilot project case study which entails data collection from the users via interviews. Analysis and findings of the qualitative data contribute towards the development of the final version of the proposed system.

Chapter 8: This chapter introduces validation of the final version of the developed system with a sample of users that represent potential users of the system in a real-life case study. The findings of the data collected via online surveys from the users of the final version of the system are discussed which shows that the developed system is ready to be rolled-out for construction projects to detect and notify the delays to the decision makers once occurred.

Chapter 9: Presents the research conclusion and recommendations for future projects and the limitations of this study.

1.10 Chapter summary

This chapter provides an insight to the implications of time delays and cost overrun on the construction industry. Initial investigations found construction delays an endemic problem that hampers the accomplishments of aspired developments. Despite the tangible consequences of delays on the construction industry, it is still an interminable unresolved issue. Furthermore, this chapter included the research aim and objectives. The following two chapters will introduce greater insight into the disparities between knowledge and the futile solutions previously developed for recovering the delays in construction projects.

Chapter 2- Construction project overruns and their consequences

2 Introduction

This chapter provides comprehensive review of the literature pertaining to the delays in the construction projects and the consequences and root causes of delays within the construction industry. The literature review presented in four sections. The first introduces definitions and statistical records of the negative impact from time delays in construction worldwide. The second part presents cost overrun, contractual disputes, poor productivity, unsatisfied clients and pressures on the national economy as consequences of time delays on the construction industry. The third part reviews literature from multiple countries concerning the root causes of delays. Finally, this review introduces the prevailing approach that seeks to monitor and control construction site activities, presenting in detail the processes of this approach and its limitations.

2.1 Overview of delays in the construction industry

The construction industry is recognised as complex, dynamic and fraught with uncertainties. Typically, construction projects incorporate multiple stakeholders with diverse objectives, power and influences (Lu *et al.,* 2008; Ahiaga-Dagbui and Smith, 2014; McCord *et al.,* 2015).

Predominantly, the performance of projects that the construction industry delivers affects its reputation. Therefore, it is commonly acknowledged that a project is successful, if it is delivered on time within budget and according to specifications of the desired quality these three criterions are so called the Iron Triangle (Chan and Kumaraswamy, 2002; Frimpong *et al.,* 2003; Faridi and El-Sayegh, 2006; Mohammed and Isah, 2012; Chih and Zwikael, 2015; Gebrehiwet and Luo, 2017). As construction projects have increasingly become more complex and more competitive, on time delivery of projects has become the biggest challenge (Kerzner, 2013). Accordingly, project delays have been considered as one of the most significant hurdles that affects the performance of the construction industry (Al-Momani, 2000; Flyvbjerg, 2005; Marzouk *et al.,* 2014; Mpofu *et al.,* 2017; Adam *et al.,* 2017; Arditi *et al.,* 2017).

Several extensive studies conducted over a span of five decades revealed that, delays in construction projects is a global phenomenon (Baldwin, 1971; Kraiem and Diekmann, 1987;

Mezher *et al.,* 1998; Lo *et al.,* 2006; Sweis *et al.,* 2008; Doloi *et al.,* 2012; Zidane and Andersen, 2018; Chalekaee *et al.,* 2019). Consequently, for decades delays in construction projects have caught the attention of researchers.

Researchers have developed several definitions for the delay in delivering construction projects. Delays can be defined as 'the act of slowing down construction progress which poses deviation from the planned construction schedule' (Bartholomew, 1998). Enshassi *et al*., (2009) characterised delays as 'any event that inhibits the construction progress in the project.' Furthermore, Mohamad (2010) defined construction project delays as 'the extension of time beyond the original completion date required to perform and complete an act or event under the contract.' Similarly, Mukuka *et al.,* (2015) defined delays 'as any slippage over the planned project schedule.'

However, consensus has been reached among the vast majority of researchers describing delays in construction projects as "*any slippage of time beyond the delivery date that is stipulated in the contract or beyond the completion date agreed by all parties for the delivery of the project*" (Assaf and Al-Hejji, 2006; Motaleb and Kishk, 2010; Mohammad, 2010; Pourrostam and Ismail, 2011; Kikwasi, 2012; Shahsavand *et al.,* 2018).

Three decades ago, in their global study, Morris and Hough (1987) examined more than 3500 large projects from different construction sectors in several countries. They reported that all the projects studied suffered from time delays varying between 40% to 200% against their planned project duration. A similar trend was revealed by a comprehensive international case study conducted by Flyvbjerg (2005), who investigated multiple construction projects in more than 20 countries over a span of 70 years. His research revealed that many iconic projects suffered from delays such as Central Artery/Tunnel Project (USA), the Channel tunnel between the UK and France, Denver's international airport, Brooklyn Bridge in New York, Big Ben in London, and the Sydney Opera House. In his research Flyvbjerg (2005) concluded that 90% of mega projects have suffered from time delays. In a different study conducted in the Middle East by Assaf and Al-Hejji (2006) whereby several construction projects were reviewed in the Kingdom of Saudi Arabia (KSA); it was found 70% of construction projects experienced time delays. Likewise, Al Turkey (2011) studied different sectors within the KSA and concluded 97% of construction projects experienced time delays.

However, for the Australian construction industry Dawson (2007) argued that, 50% of all projects in Australia with a budget over $500 million suffered from schedule delays.

A comprehensive study conducted by Companies' public annual reports in 2013 which included more than 50 countries globally, reported that 98% of construction projects experienced on average a 20 month delay from their original schedule.

An universal study conducted by Adam *et al.,* (2016) investigated both developed and developing countries from five continents and concluded that delays beyond the original contracted duration remain one of the most formidable problems for the construction industry worldwide. Similarly, a recent study conducted by Banaszak *et al.,* (2017) affirmed that 90% of the public infrastructure megaprojects experienced slippage beyond the original schedule.

In fact, there are plethora of evidences affirm that, time delays is a common persisting problem for the universal construction projects in the UK (Agyekum-Mensah and Knight, 2016), China (Ansar *et al.,* 2016), Australia (Love *et al.,* 2012), Netherlands (Cantarelli *et al.,* 2012), Turkey (Kaza *et al.,* 2012), USA (Tafazzoli and Shrestha, 2017), UAE (Al Nahyan and Sohal, 2012., Mpofu *et al.,* 2016), Egypt (Aziz and Abdel-Hakam, 2016), KSA (Assaf and Al-Hejji, 2006; Mahamid, 2016), India (Doloi *et al.,* 2012), Norway (Zidane and Andersen, 2018), Hong Kong (Lo *et al.,* 2006) and many other countries.

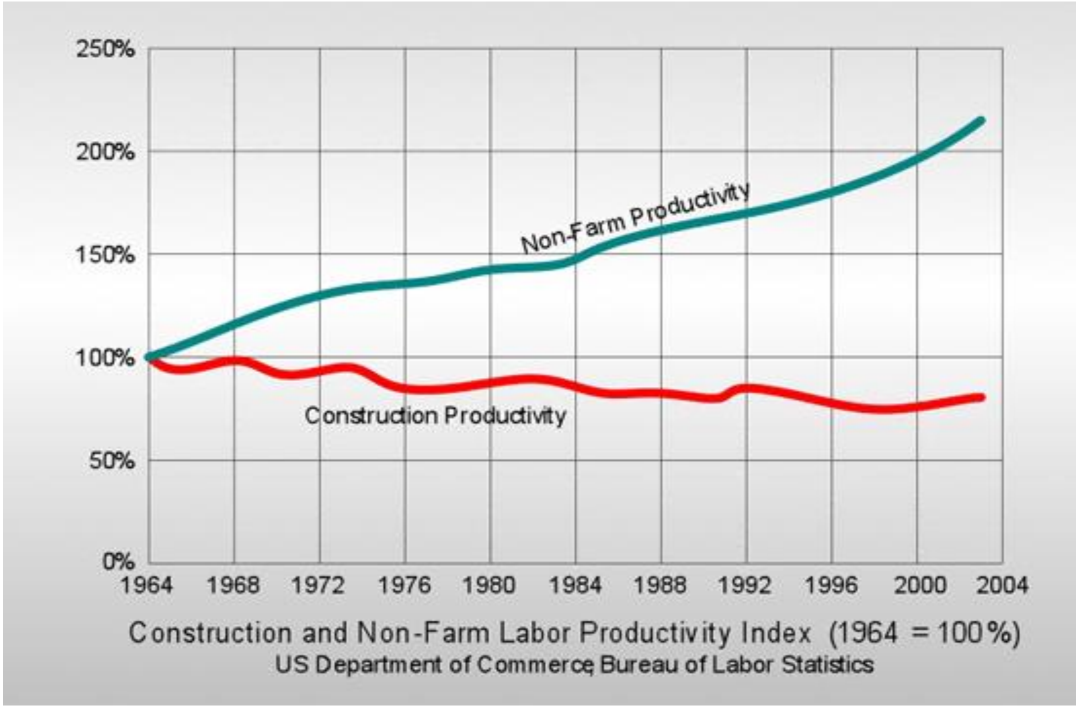
2.2 Consequences of time delays on the construction industry

Several researchers have established that it is difficult to avoid time delays in construction projects (Assaf *et al.,* 1995; Koushki *et al.,* 2005; Doloi *et al.,* 2012; Ruqaishi and Bashir 2015) and delays in any construction schedule are inevitable (Zidane and Andersen, 2018). Delays in construction projects have pervasive consequences such as low productivity rates (Sumarningsih *et al.,* 2016; Nojedehi and Nasirzadeh, 2017), late completion of the project (Doloi *et al.,* 2012; Agyekum-Mensah and Knight, 2017), cost overrun (Odeh and Battaine, 2002; Kim *et al.,* 2008), contractual and personal disputes (Jaffar *et al.,* 2011; Cheung and Pang, 2013), arbitration or litigation (Gregory-Stevens *et al.,* 2015; Cheung and Li, 2018) and sometimes termination of the contract (Abdul-Rahman *et al.,* 2006).

2.2.1 Low productivity

Over the last six decades, a significant amount of research has been undertaken in addition to historical records evidencing the poor performance of the construction industry worldwide. This demonstrates that the construction industry suffers from low productivity rates compared with other industries such as manufacturing (Allen, 1985; Teicholz, 2013; Sezer and Bröchner, 2014; Sveikauskas *et al.,* 2014; Nazarko and Chodakowaska, 2015;

Labonnote *et al.,* 2016). Therefore, improving the construction productivity is a complex topic.



Source: US department of commerce Bureau of labour statistics, permission not required as it is a public domain

Figure 2. 1: Construction industry poor performance (1964-2004)

The above Figure 2. **1** shows that over several decades, poor performance in the construction industry is a persistent problem compared with other industries such as manufacturing.

According to Ailabouni *et al.,* (2009) and Shahata and Zayed (2011) attainment of high-level productivity in construction is subject to the level of control and management of project resources. Traditionally, the cost of project resources (i.e. manpower, machines, equipment and tools) represents 50-60% of the project total budget (Adrian, 1987; Hanna, 2001; Nagaraju *et al.,* 2012). In the same context, several researchers claim that the direct capital cost for labour accounts for 40-60% of the projects' total cost (Gomar *et al.,* 2002; Hanna *et al.,* 2002; Ng *et al.,* 2004). Consequently, poor management of project resources resulting in wrong resource allocation, caused not only a drastic increase in the delays but also adds unaccounted costs to the project (Kumaraswamy and Chan, 1998). Supporting, Abdel-Wahab and Vogl (2011) argue that an increase of 10% on labour productivity in the UK construction industry creates a saving of £1.5 billion.

Research conducted by Shi and Halpin (2003) attested that accurate planning of project resources is fundamental for improving construction productivity and ultimately is a main contributor to ensuring project success. Typically, improved rate of productivity makes a paradigm shift for the construction industry performance. Therefore, early detection of delays assists the project manager to appropriately allocate resources (Naoum, 2015).

Commonly, poor management strategies that lack the capability to instantaneously detect potential delays are the main reason for project delays in the construction industry as it is often time-consuming and prone to errors (Yang *et al.,* 2015; Omar *et al.,* 2018). Consequently, unrecovered delays lead to low productivity rates and ultimately poor performance of the construction industry.

Subsequently, delays in construction projects tend to exceed stipulated completion date and overrun beyond the planned budget.

2.2.2 Time delays and cost overrun

Poor quality and cost overruns are recorded as the most common consequences resulting from delays incurred in construction projects (Arantes *et al.,* 2015). Several researchers have established a strong proportional relationship between time delays, poor quality and additional costs to the original project budget. According to PMBOK® Guide (2006, p.8) *"If the schedule is shortened often the project budget increased to add additional resources to complete the same scope of works in less time".*

As a result, any action to recover the incurred delays usually results in additional costs to the original contract value (Akinci and Fischer, 1998; Bhargava *et al.,* 2010; Anastasopoulos *et al.,* 2012; Adam *et al.,* 2015). "*Cost overrun*" is defined as any additional cost over the budgeted contract value, required to complete the project (Sunjka and Jacob, 2013).

In their study, Skamris and Flyvbjerg (1997) confirmed that due to failure in delivering projects on time, the majority of construction projects exceed their initial budgets with a cost increase between 50% and 100%, and sometimes beyond 100%.

Flyvbjerg (2005) in his comprehensive study concluded that due to time delays, owners for the following projects have incurred additional costs. The Central Artery/Tunnel Project (USA) was completed 275% over the planned budget, adding $11 billion to the projects' original value whilst the Channel tunnel between the UK and France reported a slippage of 80% over budget, adding $4.5 billion to the original project value. Furthermore, the study included the construction of Denver international airport which had a cost overrun close to 200%. His analysis of other project delays for international iconic projects such as the Brooklyn Bridge in New York revealed a 100% cost overrun compared with the original budget. Likewise, Big Ben in London recorded a cost overrun of 200% and the Sydney Opera House a 1400% cost overrun.

Typically, failure to complete projects within the planned timescale exposes the projects' client and main contractor to contractual and personal disputes. According to Abdul-Rahman *et al.,* (2006) delays are considered the major cause of construction claims.

2.2.3 Implications of time delays on contractual disputes in construction projects

According to the Construction Industry Forum (2001) of Ireland the cost of disputes in the construction industry accounts for 2% of its annual turnover. However, the construction industry's average profit margin is only 3% per annum (Gregory-Stevens *et al.,* 2015). In a later study conducted by Abeid *et al.,* (2003), it was reported that due to the incurred delays in the construction industry, the fees paid to lawyers for dispute settlement had increased by 425% between 1979 and 1990. Evidently, contractual disputes cause drastic losses to the construction industry's annual profits. Typically, "progress delays" ranked as the main cause of dispute among project stakeholders, and more specifically between the client and the main contractor (Cakmak and Cakmak, 2014).

Although, dispute in construction is widely investigated and extensively studied, there is no definitive articulation for the term *"dispute"*. However, to define *"dispute"* it is necessary to understand the meaning of *"conflict"* as they are interchangeable in common parlance.

There is a consensus among researchers and industry practitioners that, *"conflict"* exists whenever there is incompatibility of interests between individuals (Kumaraswamy and Yogeswaran, 1998; Acharya *et al.,* 2006; Murdoch and Hughes, 2008; Cheung and Pang, 2013). According to Murdoch and Hughes (2008) conflict is the expression of different opinions about the same issue concerning the project. They considered conflict as a healthy phenomenon since it remains manageable, whilst some researchers claimed that, conflict contributes to solving technical problems. This claim was elaborated on, proposing that as the client appoints a team of professionals to give advice, each with specialist knowledge and proposing a solution from their perspective will inevitably result in a conflict between the parties. Many researchers established that conflicts are inevitable in any construction projects (Cheung and Yiu, 2006; Jaffar *et al.,* 2011; Gregory-Stevens *et al.,* 2015; Cheung and Li, 2018).

Hellard (1987) considered dispute in construction as the opposition of interests, values and objectives. Bristow and R. Vasilopoulos (1995) and Sykes (1996) defined dispute as unrealistic personal expectations that diminishes the team spirit and promotes misunderstanding. Moreover, Brown and Marriott (1999) defined dispute as a kind of conflict that requires resolution. Similarly, Murdoch and Hughes (2008) and Cakmak and Cakmak (2014) established that any unmanaged conflict quickly turned into a dispute.

Traditionally, construction projects tend to suffer from delays and cost overruns; and consequently, there is no project free from disputes. Disputes are classified essentially into two types; the first type that can be settled within the project team without third party intervention. However, the second type is associated with judicial issues which require resolutions such as mediation, arbitration or litigation (Hill, 2008; Trushell *et al.,* 2016; Aryal and Dahal, 2018).

2.2.3.1 Dispute resolution: Mediation, Arbitration and Litigation

Usually within the contractual agreement the course of actions and procedures required for dispute resolution are outlined. However, the most common forms of dispute settlement are mediation, arbitration and litigation. Under Table 2.1 the main features of each type of dispute resolution are laid out, that is, definition and procedures.

Table 2.1: the main features for dispute resolution

	Mediation	**Arbitration**	**Litigation**
Definition	The art of changing a person's position with the involvement of a third party to act as a mediator, aiming to reach an amicable arrangement between parties with legal disputes. The mediator endeavours to find agreement between parties by attempting to settle the claim for reinforcements and the areas of dispute to seek a fair outcome which is accepted by all parties. The mediator confirms their recommendations	A formal mechanism of dispute resolution involving a third party, the arbitrator. The arbitrator could be a person, or a panel of arbitrators that make a decision which is binding for the disputing parties outside the courts (Murdoch and Hughes, 2008; Aryal and Dahal, 2018).	A legal proceeding conducted in a judicial court to judge and enforce the legal rights of the relevant parties (Hill, 2008)

	based on their findings. If both parties accept the decision to settle the dispute, they will be bound by this decision and the action/s required will be added to the contract as an addendum to the contract (Alper and Nichols, 1981; Hill, 2008; Murdoch and Hughes, 2008; Trushell *et al.,* 2016).		
Procedures	Although there are no fixed procedures to be followed for mediation; it is usually contains several meetings between the mediator and both parties independently. The mediator will have meetings with each party separately but at the same venue during the same time period. By using this method, the mediator can quickly work between both parties to establish a resolution at a relative pace. Based on the points in agreement and dispute, the mediator offers options for both parties to agree	Arbitration procedures tend to vary from one country to another. However, the principles of any arbitration process remains similar. This process starts with a formal submission of the claim (the points of dispute) from both parties. Each party must substantiate his claim with up-to-date records and evidence. The arbitrator(s) study the submitted documents and may or may not request additional documents that enable him/her to take a decision. The decision issued by the	Litigation procedures often vary from country to country and even state to state. However, in all cases there is a certain course of procedures and actions that should be followed during the litigation process (Murdoch and Hughes, 2008). Once a lawsuit has been submitted by the complainant both parties officially submit their evidence in support of their case to the judge/s through specialised lawyers. The judge/s will evaluate both sides arguments to evaluate

	upon. If both parties agree an outcome; the mediator may have a meeting with both parties present to conclude and sign-off on the amicable settlement agreement. (Murdoch and Hughes, 2008; Trushell *et al.*, 2016).	arbitrator is binding to both parties and they have no right of appeal on the arbitrator's decision (Murdoch and Hughes, 2008; Aryal and Dahal, 2018).	and make their decision. It is likely there are a number of appeal stages available which will result in the same principle as outlined above being applied (Murdoch and Hughes, 2008). Once the appeals process has been exhausted the judge's final decision is binding to both parties.

Over a span of seven years from 2010 to 2017, Arcadis management consulting company studied the consequences of delays in several construction projects and the resulting disputes worldwide via their report dubbed *"Global Construction Dispute Report"*. The report defined the term "*dispute value"* as the additional monetary amount over and above which is included in the contract, for the incident` which is being claimed for recovering the incurred delays. And the "*dispute length"* is the period of time between when the delay becomes formalised under the contract, and the time of settlement or the conclusion of the hearing. The following tables Table 2.2 and Table 2.3 show the average "*dispute value"* and "*dispute length"* respectively, in selected countries and/or geographical areas.

Table 2.2: Dispute value for some countries

Year / Region	**Dispute value (US $ Million)**							
	2010	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**
UK	7.5	10.2	27	27.9	27	25	34	34
North America	64.5	10.5	9	34.3	29.6	25	21	19
Continental Europe	33.3	35.1	25	27.5	38.3	25	19	29.5
Middle East	56.3	112.5	65	40.9	76.7	82	56	91

Global Average	**40.4**	**42.1**	**31.5**	**32.7**	**42.9**	**39.3**	**32.5**	**43.4**

Table 2.2 reveals that the dispute adds an average of **$ 38.1 million US dollars** to original contract values for the construction industry worldwide.

Several researchers estimated the direct cost associated with disputes in the construction industry ranged from 0.5% to 5% of the original contract value (Chan and Kumaraswamy, 1997; Aryal and Dahal, 2018). The following Table 2.3 determines dispute length within the same parameters as Table 2.2.

Table 2.3: Dispute length for some countries

Year / Region	Average Dispute length (Months)							
	2010	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**
UK	6.8	8.7	12.9	7.9	10	10.7	12	10
North America	11.4	14.4	11.9	13.7	16.2	13.5	15.6	17.7
Continental Europe	10	11.7	6	6.8	18	18.5	14.1	18.1
Middle East	8.3	9	14.6	13.9	15.1	15.2	13.7	13.5
Global Average	**9.1**	**10.6**	**12.8**	**11.8**	**14.8**	**14.5**	**13.9**	**14.8**

Similarly, Table 2.3 shows disputes on average adds a further **12.8 months** to the original contract duration for the construction industry worldwide.

Evidently, delays in construction can lead to disputes which cause significant losses for the construction industry not only in annual profits, but also personal tensions, hostile relationships, mistrust and potential breakdown in collaboration among the project stakeholders.

Several researchers have studied the implications of disputes due to delays, on construction project stakeholders. Furlong (2005) and Acharya and Lee (2006) and Sayed-Gharib *et al.*, (2010) found that disputes will usually lead to project disruption, money loss and detrimental relationships between project participants. Within the same context, Aryal and Dahal (2018) asserted that disputes often accompanied the end of good working relationships amongst the project team. In some cases, the consequences of disputes can even lead to project suspension or shut down (Awakul and Ogunlana, 2002).

Ultimately, disputes in construction have devastating implications on both the contractors' and clients' reputation. Typically, disputes tarnish the reputation of both disputant parties and often affects current and future business opportunities in procuring new projects (Mackie *et al.,* 1995; Chan and Kumaraswamy, 1997; Aryal and Dahal, 2018).

2.2.4 Implications of time delays on the contractor

As soon as the project owner discovers the delays in a project, they will impose significant pressure on the contractor to recover the incurred delays. Accordingly, the contractor will expedite productivity rates by pursing one or more of the most commonly used options within construction projects.

Hanna *et al.,* (2008) claimed that, there are three options available to the contractor to recover the delays and accelerate the construction schedule as follows:

Option 1, working longer hours (overtime), in this case the contractor extends his duty beyond the normal working hours with the same resources to increase his daily productivity. This option is commonly followed to recover minor delays that require quick and temporary actions.

Option2, additional resources during working hours: this is the most used option for recovering the non-heavy delays whereby, the contractor adds additional resources (i.e. manpower, machines, equipment and tools) to recover the incurred delays.

Option 3, additional resources beyond working hours (night shift): In addition to normal working hours the contractor adds extra time beyond the normal daily working hours by introducing a night shift. Predominantly, this option is followed to recover the critical and/or heavy delays.

In all cases the contractor has to bear the unaccounted additional costs for workforce, machines, equipment and even sometimes for the client and supervision staff to inspect the work after their normal duty hours (Noyce and Hanna, 1998; Jun and EL-Rayes, 2010). These extra costs will usually result in turning the contractor's planned profits into losses (Hanna *et al.,* 2008; Gluszak and Lesnaik, 2015). The contractor will use all contractual and legal means available to him to recover loss of profits. And typically, contractors will claim against the client for either Extension of Time (EoT) or compensation for additional costs and in some cases both to recover the incurred losses (Aryal and Dahal, 2018). If the client accepts the contractor's claim, which rarely happens, the claim is settled.

However, in most cases the client is unlikely to accept claims made by the contractor due to difference in perception of the claimants' entitlement interpretation. Typically, the client

considers any time delays are the fault of the contractor. Subsequently, the dispute becomes unsettled and requires involvement from a third party to act independently, judging the entitlement of the raised claim as being mentioned in above section 2.3.3.
In fact, the competitive nature of the construction industry adds tremendous pressure on the contractor to find ways to gain competitive advantage, thus ensuring business sustainability. In this sense, Karna *et al.,* (2009) found that client satisfaction is paramount to an organisations' success and sustainability, whereas, added competitive advantage leads to the client's preference for a certain contractor to award a long term contract agreement or during the bid evaluation. However, disputes resulting from delays in construction progress are the main source of the breakdown of relationships between the main contractor and the client.

2.2.5 Implications of time delays on clients

Inevitably, time delays in construction projects lead to cost overrun whereby, the client is often required to source additional funds to complete the project (Mukuka *et al.,* 2015). Sometimes, clients fail to persuade their financial institutions or investing partners for additional funds which results in suspension of the project. Consequently, from the owner's perspective failure to deliver the project on time results in a loss of projected revenues and thus profits. This is due to the facility not being ready to either rent or sell in the case of dwellings or hotels or not being able to sell products if the project relates to a construction project for the manufacturing industry (Kikwasi, 2012; Ramanathan *et al.,* 2012).

However, the consequences are significantly worse for public projects such as hospitals, schools, universities, roads, railways, airports, etc.; these projects are intrinsically linked to the development of national infrastructure aimed to serve the public and to lift the national economy (Assaf and Al-Hejji, 2006; Agyekum-Mensah and Knight, 2017).

Conversely, several studies have established that client satisfaction is seldom accomplished for construction projects. Maloney (2000) defined client satisfaction as the level of satisfaction for the service provided by the contractor or any other service provider involved in ensuring the construction project completion. In his celebrated report Latham (1994) concluded that, one of the most predominant weaknesses within the construction industry is "*client dissatisfaction*". Only four years after Latham's report, Eagan (1998, p.7) concluded that, the causes of client dissatisfaction are cost overrun, time delays and poor quality.

Researchers have proposed numerous criterions for measuring the client satisfaction, Holt *et al.,* (2000) claimed that, project cost is the true indicator for measuring the client satisfaction. However, Ling and Chong (2005) argued that, the quality is more comprehensive and more appropriate to measure the client satisfaction. A comprehensive study conducted by Karna *et al.,* (2009) included 22 indicators for measuring client satisfaction and concluded that, less cost, high levels of quality, and undertaking projects within shorter timescales are the most important indicators for client satisfaction.

Fundamentally, failure to complete projects on time leads to client dissatisfaction (Mashwama *et al.,* 2017). Whilst, saving cost and time in addition to better quality are the most common benefits for any construction project, yet, the ultimate goal is to make the client happy and satisfied.

Clearly, the implications of time delays in construction projects are extended to include a negative impact on the national economy alongside the whole construction industry due to profit losses, time extensions, disputes, bad reputation and less opportunity to win new contracts.

2.2.6 Implications of time delays on the national economy

The construction industry is a vital component of and key contributor for ensuring the sustainability of global economic outputs. Rhodes (2015) reported in his study of the construction industry’s contribution to the UK economy, that the construction industry plays an essential role in propping up the UK economy, wherein the UK construction sector in 2014 contributed £103 billion to economic output equating to 6.5% of the total economy. In addition, 2.1 million of direct jobs in the UK were employed within the construction sector for the first quarter of 2015 which represented 6.2% of the UK’s total workforce.

Likewise, the construction industry is the second largest contributor to the national economy in India and Cambodia with 8-10% contribution to the national Gross Domestic Product (GDP) (Doloi *et al.,* 2011; MEF, 2016). In Australia it is the fourth largest contributor with 7% of GDP and 10% of workforce (French and Strachan, 2015). Its contribution to the UAE national GDP hits 14%, whilst 22.1% of the overall workforce is employed by the construction sector (Faridi and El-Sayegh, 2006; UAE Annual Economic Report, 2013).
In a more recent study conducted by Kim *et al.,* (2015) it was concluded that the construction industry contributes 10% to the GDP in developed countries and 25% in developing countries.

Therefore, many researchers argued that investing in the construction sector is the main catalyst for national economic growth (Turin, 1973; Turnovsky, 1997; Perkins, 2005; Delgado and Alvarez, 2007). According to Horner and Duff (2001) the benefits acquired for any improvement within this sector is not limited to raising profits and earnings within the construction industry, but extends to include a positive effect on the overall national economy. According to (US department of commerce report, 2011), every one-billion-dollar spending in the construction industry creates approximately 47,000 jobs .

Clearly, there is significant research that offers irrifutable evidence of the importance of the construction industry to national and international economies, and accordingly, any improvement will be positively reflected in the economy. In the study conducted by Rhodes (2015), it is claimed that as part of the UK policy to create more employment, the government invests in construction projects.

However, the unmanaged delays hinder the construction industry's ability to effectively fulfil its fundmental role in boosting the national and international economy (Doloi *et al.,* 2012; Kim *et al.,* 2015). Moreover, the comprehensive study conducted by Doloi *et al*., (2012) affirmed that, implications of delivering construction projects beyond its original schedule is not limited to only the project stakeholders; its implications tend to affect construction industry as a whole and the national economy.

Therefore, recognition of the root causes of delays in construction projects will enable the proposition of appropriate management tools to detect and report delays instanteously. This will offer a greater opportunity to save time and cost, improve productivity, promote client satisfaction, reduce the level of disputes and ultimately increase the output of the national GDP for development of the country.

2.3 Root causes of delays in construction projects

Clearly, project delays in the construction industry are a global phenomenon. The key root causes of project delays, as recognised from the available literatures are summarised in Table 2.4.

In light of the comprehensive literature review that was conducted, it is concluded that the causes of delays in the construction industry can be classified into eight main categories, which leads to 37 different consequences. Table 2.4 demonstrates the causes and effects of the delays in construction projects which start by "***Financial issues***". Indeed, financial issues are one of the most common causes for delays in construction, whereby any shortage of the funding flow from the client to the contractor often affect the contractor's ability to continue funding the project. Consequently, financial issues usually lead to project slow-down due to the contractor's inability to pay off the subcontractors and bear the cost of heavy machines and superintendents (Lo *et al.,* 2006; Kazaz *et al.,* 2012; Zidane and Andersen, 2018).

"***Inadequate contractor's experience*****"** was identified as one of the major causes of construction delays and has adverse impact on construction projects. Assaf and Al-Hejji (2006) and Agyekum-Mensah and Knight (2017) claimed that, poor site management and weak supervision by the contractor are the main causes of the expected consequences of ineffective monitoring and controlling systems which inevitably causes time delays. In the same context, various researchers confirmed that ineffective planning and scheduling, and poor productivity are direct consequences of the contractor's poor experience (Sweis *et al.,* 2008; Kazaz *et al.,* 2012; Emam *et al.,* 2015; Aziz and Abdel-Hakam, 2016).

Moreover, "***Inadequate client experience***" is a common root cause for delays in construction projects, wherein, client's inadequate experience affects the project in its early stages, starting from pre-tender stage to the operation and maintenance stages. Koushki *et al.,* (2005) and Senouci *et al.,* (2016) examined the consequences of inadequate client experience and found that unclear initial project objectives and scope definitions, in addition to an unrealistic contractual timeframe, are of key importance and are common causes that lead to project delays. Furthermore, an inexperienced client is usually reluctant to take decisions, which results in slow decision-making, that will culminate in delays as well as numerous claims and conflicts between parties (Tafazzoli and Shrestha, 2017; Zidane and Andersen, 2018).

Likewise, "***inadequate designer experience****"* is another key factor that causes delays in construction projects. These factors are associated with design issues, such as errors in design, incomplete drawings or conflicts between what has been drawn and the specifications, as well as drawings being unavailable when required (Aibinu and Odeyinka, 2006; Doloi *et al.,* 2012; Aziz and Abdel-Hakam, 2016; Tafazzoli and Shrestha, 2017).

During the construction stage, "***communication barriers***" are sometimes deemed significant causes of project delays, which are often associated with the diversity of language, in addition to the paradoxes and contradictions that emerge from heterogeneous cultures of the manpower. This is in addition to the unsuitable medium of communications between the project team. Senouci *et al*., (2016) and Mahamid (2016) reported a lack of communication between parties, in addition to understanding coordinating roles and responsibilities amongst the personnel involved often leads to inappropriate resource management, that result in project delays.

Another common cause of project delays is "***Inadequate site investigation before the bidding process****"* which usually results in design changes and variation orders that inevitably lead to time delays and cost overrun. "***Adverse weather"*** conditions, wherein hot countries such as KSA, Kuwait, Qatar, Oman and UAE, often lead to the interruption of works during the mid-day especially during the summer season. The government usually issues decree for labourers, construction workers and other out-of-office workers prohibiting any work under the direct sun to avoid sunstroke. Consequently, the rate of productivity for the construction project is affected and when such a situation is not managed it results in extreme delays (Al-Nahyan and Sohil, 2012; Ruqaishi and Bashir, 2015; Senouci *et al.,* 2016; Mpofu *et al.,* 2017).

Another pressing issue which causes delays in construction projects, is caused by "***Delays in obtaining approvals or releasing No Objection Certificates (NOC) /*****work permits** ***from government/ other authorities"***, which tends to have a direct impact with a partial suspension or slowdown of the construction project until approval has been obtained from relevant authorities (Aibinu and Odeyinka, 2006; Sambasivan and Soon, 2007; Aziz and Abdel-Hakam, 2016; Mahamid, 2016; Mpofu *et al.,* 2017; Tafazzoli and Shrestha, 2017).

The following Table 2.4 summarises causes of delays which are aggregated from several countries, showing the category of the delays, causes of delays, relevant countries and their respective authors.

Table 2.4: Causes of construction project delays

Category of delays	**Causes of project delays**	**Country**	**Sources**
Financial issues	1. Delay of payments by owner. 2. Inadequate resources due to contractors' lack of capital.	KSA	Assaf *et al*., (1995); Assaf and Al-Hejji (2006); Mahamid (2016)
		Lebanon	Mezher *et al*., (1998)
		Jordan	Sweis *et al.,* (2008)
		Kuwait	Koushki *et al*., (2005)
		Egypt	Aziz and Abdel-Hakam (2016)
		India	Doloi *et al*., (2012)
		Palestine	Mahamid *et al*., (2012)
		Turkey	Kazaz *et al.,* (2012)
		Nigeria	Aibinu and Odeyinka (2006)
		Norway	Zidane and Andersen (2018)
		Malaysia	Sambasivan and Soon (2007)
		Hong Kong	Lo et al., (2006)
	1. Poor site management and supervision. 2. Poor productivity. 3. Ineffective planning and scheduling.	KSA	Assaf *et al.,* (1995); Assaf and Al-Hejji (2006)
		Jordan	Sweis *et al*., (2008)
		Egypt	Marzouk and El-Rasas (2014); Aziz

Inadequate contractor's experience	4. Problems with subcontractors. 5. Ineffective monitoring and control systems. 6. Slow mobilisation. 7. Shop drawings issues.		and Abdel-Hakam (2016)
		Oman	Ruqaishi and Bashir (2015)
		Qatar	Senouci *et al.,* (2016) ; Emam *et al*., (2015)
		Turkey	Kazaz *et al.,* (2012)
		Nigeria	Aibinu and Odeyinka (2006)
		Hong Kong	Chan and Kumaraswamy (1996); Lo *et al.,* (2006)
		UK	Agyekum-Mensah and Knight (2017)
		Norway	Zidane and Andersen (2018)
		Malaysia	Sambasivan and Soon (2007)
		Lebanon	Mezher *et al.,* (1998)
Inadequate client's experience	1. Unrealistic contract duration. 2. Slow decisions by owner. 3. Unclear scope definition. 4. Unclear initial project objectives. 5. Delays in design approvals by owner. 6. Changing orders from client during construction. 7. Conflicts and disputes between parties.	KSA	Assaf *et al.,* (1995); Assaf and Al-Hejji (2006); Mahamid (2016)
		Lebanon	Mezher *et al.,* (1998)
		Jordan	Sweis *et al.,* (2008); Al-Momani (2000)
		Kuwait	Koushki *et al.,* (2005)
		Egypt	Marzouk and El-Rasas (2014)
		India	Doloi *et al.,* (2012)
		Qatar	Senouci *et al.,* (2016); Emam *et al*., (2015)
		Hong Kong	Lo *et al.,* (2006)
		UK	Agyekum-Mensah and Knight (2017)
		Norway	Zidane and Andersen (2018)
		USA	Tafazzoli and Shrestha (2017)
Inadequate designer's experience	1. Design errors. 2. Unavailability of drawing/design on time. 3. Incomplete drawings. 4. Changing orders during construction.	Egypt	Aziz and Abdel-Hakam (2016)
		India	Doloi et al., (2012)
		Turkey	Kazaz *et al.,* (2012)
		Nigeria	Aibinu and Odeyinka (2006)
		USA	Tafazzoli and Shrestha (2017)
		KSA	Mahamid (2016)
		Qatar	Senouci *et al.,* (2016)

Communication barriers and unclear channels	1. Lack of communication between construction parties. 2. Wrong allocation of roles and responsibilities among involved parties. 3. Communication barriers and inappropriate resource management.	UK	Agyekum-Mensah and Knight (2017)
Adverse weather conditions	1. Site closures. 2. Poor productivity.	Jordan	Sweis *et al*., (2008); Al-Momani (2000)
		KSA	Assaf and Al-Hejji (2006); Mahamid (2016)
		Kuwait	Koushki *et al.,* (2005)
		Oman	Ruqaishi and Bashir (2015)
		Qatar	Senouci *et al*., (2016)
Inadequate site investigation before the bidding process	1. Unforeseen site conditions resulting in design changes and variation orders.	KSA	Assaf *et al.,* (1995); Assaf and Al-Hejji (2006) ;Mahamid (2016)
		Lebanon	Mezher *et al*., (1998)
		Jordan	Sweis *et al*., (2008); Al-Momani (2000)
		Kuwait	Koushki *et al.,* (2005)
		Egypt	Marzouk and El-Rasas (2014)
		Oman	Ruqaishi and Bashir (2015)
		Qatar	Senouci et al., (2016)
		Nigeria	Aibinu and Odeyinka (2006)
		UK	Agyekum-Mensah and Knight (2017)
		USA	Tafazzoli and Shrestha (2017)
Delays in obtaining approvals or releasing NOCs/work permits from government/ other authorities	1. Bureaucracy and lengthy procedures.	KSA	Assaf *et al.,* (1995); Assaf and Al-Hejji (2006); Mahamid (2016)
		Lebanon	Mezher *et al.,* (1998)
		Jordan	Sweis *et al*., (2008)
		Kuwait	Koushki *et al.,* (2005)
		Egypt	Aziz and Abdel-Hakam (2016)
		India	Doloi *et al.,* (2012)
		Palestine	Mahamid *et al*., (2012)
		Turkey	Kazaz *et al*., (2012)
		Nigeria	Aibinu and Odeyinka (2006)
		Norway	Zidane and Andersen (2018)

		Malaysia	Sambasivan and Soon (2007)
		Hong Kong	Lo *et al.,* (2006)
		UK	Agyekum-Mensah and Knight (2017)
		Norway	Zidane and Andersen (2018)
		USA	Tafazzoli and Shrestha (2017)
		Malaysia	Assaf *et al*., (1995); Assaf and Al-Hejji (2006); Mahamid (2016)

As depicted in Table 2.4, the phenomenon of delays in construction projects is a universal problem, but the frequency and severity of the root causes differ from one country to another, due factors such as geographical, political, social, economic and cultural issues (Siemiatycki, 2015; Aziz and Abdel-Hakam, 2016; Mpofu *et al.,* 2017).

In a recent study sought to make sense of the underlying causes of delays in the construction industry, Zidane and Andersen (2018) examined 128 research studies across various countries, from 1985 until 2017. They concluded that all construction projects, regardless of the country's development level, face delays without exception.

The literature study suggests the top ten most common universal root causes of delays are as follows:

1) Change to orders during construction,
2) Delayed payments by owner,
3) Poor planning and scheduling,
4) Poor site management and supervision,
5) Incomplete or errors in design,
6) Inadequate experience of the contractor,
7) Contractor financial difficulties,
8) Client financial difficulties,
9) Resource shortage (human resources, machinery, equipment)
10) Poor productivity.

Moreover, there is a plethora of research that studies the root causes of delays and its implications on the project's stakeholders as well as the national and international economy. Accordingly, it is extremely important to detect the delays as early as possible to enable decision makers to make the most appropriate decisions within a timely period to recover those delays. In his research Martin (1976) ascertained that it is important to track and monitor the construction progress to reduce and manage the delays.

The late detection of delays causes a backlog of delays which often makes it difficult for recovery (Cleland, 1999; Abdul-Rahman and Berawi, 2002a; Abdul-Rahman *et al.,* 2006). Indeed, proper monitoring and controlling of construction site activities enables the contractor to recognise the activities that require extra attention, and hence the project manager will redistribute their resources to recover the detected delays in order to complete the project on time.

2.4 Approaches of monitoring the progress for detecting the delays in construction projects

The literature study shows that, numerous researchers have proposed monitoring systems sought to detect delays in the construction industry. These monitoring systems aim to enable project managers to appropriately control and manage the site activities by detecting delays in construction projects. In this context, El-Omari and Moselhi (2011) claimed that, the PM continuously needs updates using timely data of the project progress status to take actions, either to alleviate delays or to exploit the accomplishments of being ahead of the as-planned schedule.

Usually, to update the progress status for any construction project, the as-planned schedule is compared against the real as-built status (Meredith and Mantel, 2006; Gloparvar-Fard *et al.,* 2011), with the following paragraphs detailing these two terminologies.

As-planned schedule: at the pre-construction stage or just prior to starting the construction activities, the contractor usually prepares the baseline construction schedule (as-planned schedule). The as-planned schedule shows the activities in its logical construction sequence including start and finish dates, in addition to a weighting for each activity according to the contractor’s evaluations (Meredith and Mantel, 2006; PMBOK, 2017).

Normally, the project details are entered manually into a programming software package such as Microsoft project or Oracle Primavera, with the schedule encompassing several details such as, but not limited to the following;

- The sequences and logic between the activities (i.e. excavation followed by blinding concrete, then RC foundation, etc.).
- The resources available and their respective productivity rates (machines, equipment and humans).
- The duration required to complete each activity (start date, finish date and float).

- The weight given to each activity, which equates to a total 100% for all project activities.

As-built status: refers to the status of the activities during the construction, usually expressed as a percentage of completion, which may be fully completed (i.e. 100%) or partially completed and that is evaluated according to certain criteria, or not yet started. Accordingly, to update the progress status, the acquisition of site data is the main component of evaluating the percentage of completion for each activity. Generally, site data acquisition varies according to monitoring approaches employed, whereas in the manual approach it is as the name suggests, undertaken manually.

The following section will introduce the leading monitoring approaches used within the construction industry, to detect delays in construction projects.

2.4.1 Manual approach

Despite recent advances, the prevailing monitoring and management systems in the construction industry are still dominated by traditional approaches, including manual paper-pen based collection and recoding of on-site activities (Kimoto *et al.,* 2005; Golparvar-Fard *et al.,* 2009; Yang *et al.,* 2015; Omar *et al*., 2018).

The comprehensive literature review demonstrates that, all monitoring and controlling of construction site activities including the manual approach consists mainly of four processes as follows:

1. Data acquisition,
2. Data integration and preparation,
3. Data analysis and
4. Reporting.

The following section introduces the manual approach in detail, elaborating its components, benefits and limitations.

2.4.1.1 Data acquisition

Data acquisition is defined as the process of collecting data from the construction site (Cheng and Teizer, 2013). This process involves quantification and evaluation of the completed and partially completed construction elements, in addition to those activities that have not started. Data acquisition requires recording the details of as-built status for each activity in either quantities or percentage. Updating the construction progress for delay detection necessitates precise comparison between the as-planned schedule and the as-built status. Therefore, the collected data has to follow the as-planned schedule quantification system, for example the reinforced concrete for columns to be measured in cubic meters and the plain concrete for foundation measured in square meters. Accordingly, the collected data should therefore follow the same quantifications (French, 1996).

Indeed, the vast majority of construction sites are still using traditional and manual instruments and tools to measure lengths, heights, levels, coordinates and sometimes angles for data acquisition. Measuring tape, leveling instruments, theodolites and sometimes 'total stations' are still widely used in construction projects (Cheok *et al.,* 2000; Turkan *et al.,* 2013).

Typically, data collection from construction sites requires inspectors/engineers equipped with measuring and surveying tools to physically visit the site. Usually, operating these surveying instruments requires more than one person, for example, collecting measurements using the theodolite or 'total station' requires two people i.e. the surveyor and staff or prism guy (Akinci, 2006; Kim *et al*., 2008).

It is worth noting, these instruments are usually possessed by the project contractor, and therefore, the contractor tends to be the sole source of the measured as-built data and accordingly the progress updates (Vorminder, 2019).

Despite the tremendous advancements and widespread use of technology, specifically hand-held smart devices, the most commonly used method for recording collected data from construction sites is still pen and paper which is so called the "*field book*" (Beliveau, 1995; Kimoto *et al.,* 2004; Yang *et al.,* 2015; Behnam *et al.,* 2016). The field book is a note-book that site inspectors and surveyors use for noting and recording their observations, that is, the collected data. Hitherto, the field book is deemed as the reference book and the sole source for updating the construction progress (Beliveau, 1995; Zaher *et al.,* 2018).

Although, some companies sought to reduce human errors and the vast amount of missing details during data collection by replacing the field book with developed and customised checklists made ready to use (Staab, 1987; Chang *et al.,* 2012). However, the most prevalent tool for data acquisition is still the manual based approach that relies on paper and pen for recording and observing the visually inspected details.

Traditionally, data acquisition varies according to the nature and complexity of the project, and hence, evaluation of the percentage of completed and partially completed is subject to the visual inspection and inspectors' evaluation, which often varies from inspector to inspector (Chang *et al.,* 2012). Moreover, updating the progress is usually done on a weekly basis, mainly because it involves several staff for data collection who spend more than 25%

of their daily work activities collecting the data and recollecting missing details (McCullouch and Gunn, 1993; Omar *et al.,* 2018).

2.4.1.2 Limitations of manual data acquisition

Manual data collection is often cumbersome, as site managers and inspectors manually collect and record progress of site activities by filling forms in on-site, and then re-enter the collected data and interpret them at the site office (Kim *et al.,* 2008). This process is extremely slow, involves human judgment and accordingly is prone to errors as it takes approximately 20–30% of the feeders' daily efforts to update the construction activities (Golparvar Fard and Peña-Mora, 2007; Ibrahim *et al.,* 2009; Gloparvar-Fard *et al.,* 2011; Chang *et al.,* 2012; Solihin and Eastman, 2015). Manual data collection requires experienced inspectors to amass the data from busy construction sites; this task remains error prone, time consuming, labour intensive and potentially subjective (McCullouch and Gunn, 1993; Turkan *et al.,* 2012; Cheng and Teizer, 2013). Human judgments and subjectivity are correlated with the inspector's experience, background, agility and industriousness. In fact, acquiring different values for the as-built status for the same construction elements by different inspectors is common, especially for complex project with many construction elements in progress (Chang *et al.,* 2012).

In this context, El-Omari and Moselhi (2011) affirmed that, manual data collection from construction site lacks consistency and reliability. According to Chang *et al.,* (2012) they concluded that, manual data collection lacks efficiency and accuracy, with accuracy of collected data no better than 50%.

In their studies which focused on the time required to collect data on construction projects, Beliveau (1995) and Chang *et al.,* (2012) established that, manual data acquisition for construction sites requires at least one day for small projects with few activities and between two to six days for big and complex projects.

On the other hand, data acquisition often requires several inspectors collecting the data with this data in its raw form which is neither organised nor meaningful (McCullouch and Gunn, 1993; Cheok *et al.,* 2000; Chang *et al.,* 2012). Therefore, this data requires human effort and time to be modified for further processing.

2.4.2 Data integration and preparation

The collected data in its raw form is deemed inconsequential, thus, processing the data is necessary for it to be in a logical format. Data integration is defined as the process wherein the raw data is transformed to be more organised and easy-to-use (Chamberlin *et al.,* 1976).

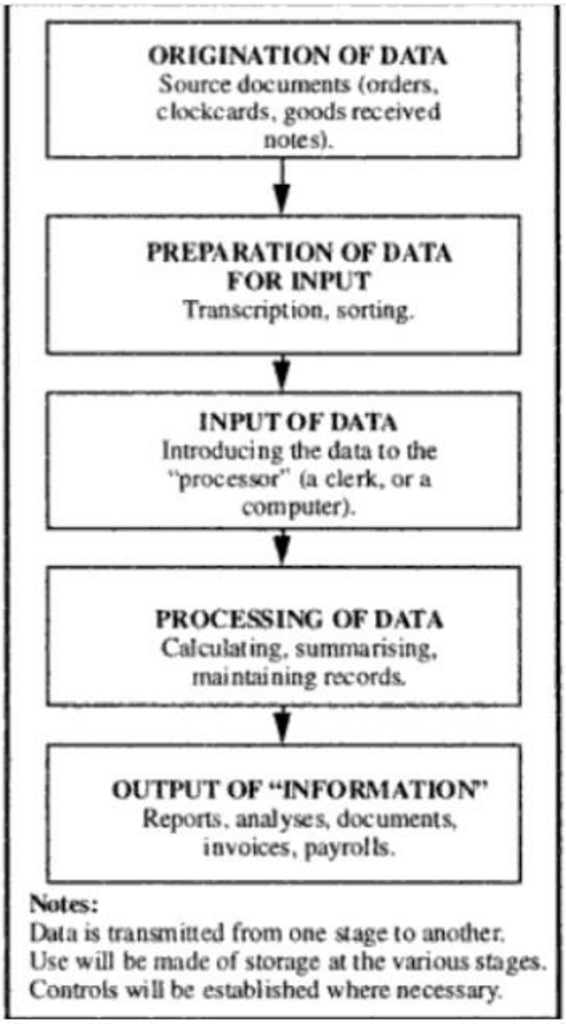
Figure 2.2 demonstrates the different processes that the collected data must undergo in order to develop meaningful information from the raw data collected from the construction site. French (1996) considers collected and processed details under the input category as "*data*". However, the output enables the development of the report that summarises the situation to support decision-makers and is so called "*information.*" French (1996) continued with his summising, considering data as the basic facts about the activities of a business and information as the data assembled in a useful form. Therefore, it is necessary to recognise the difference between "*data*" and "*information*".

Many researchers have developed various definitions for data and information. For example, Davis and Shaw (2011) defined "data" as the plural of datum, and it is a set of collected facts that were a given (accepted as "true"). However, he defined information in the sense of communicating (i.e., to report, relate, or tell) and comes from the Latin verb "*informare"*, which meant to shape (form) an idea.

According to Buckland (1991b) "*data"* is commonly used to refer to records or a recording encoded for use in a computer but is more widely used to refer to statistical observations and other recordings or evidence collection. He considered 'information' as referring to anything perceived as potentially signifying something (e.g. printed books). Similarly, Ackoff (1999) considered data as symbols that represent the properties of objects and events. Whilst, information consists of processed data, the processing directed to increase its usefulness.

Following a review of more than thirty definitions of 'data' and 'information' it revealed that, Tom Stonier's definition was found to be the most relevant to the construction project management field. Stonier (1990) defined "data" as the result of someone's observations or measurements that are recorded; these records are usually in a form of series of disconnected facts and observations. Stonier went on to define "*information"* as the end product of data processing that develops a meaningful report to support decision makers.
In the same context, Ackoff (1999) concluded, an ounce of "*information*" is worth a pound of "*data.*"
It is clear, in order to get the required construction progress report, the collected data specifically when using the manual approach has to undergo several processes.

In this context, French (1996, p.82) manifested that, conversion of raw data to meaningful facts must take place using two main processes i.e. **origination of data** and **preparation of data for input**. The following section elaborates each process.



Source: Data processing and information technology, book, used with permission from CENGAGE

Figure 2.2: Data processing

"*Origination of data*": Typically, data collected from a construction site is frequently redundant, duplicated and sometimes encompasses erratic data, as it is recorded manually and based on the inspectors' visual observations (Bhargava *et al.,* 2010; Adam *et al.,* 2015; Behnam *et al.,* 2016). The main goal of this process is to convert raw data into a suitable form for further processing. This process seeks to synthesis and refine the acquired data manually or by the use of a computer, and subsequently the collected data becomes free from redundancy or duplications and ready for further processing. This process also involves interconnecting every item in the field book with its corresponding construction element by assigning the same identification code endorsed in the as-planned construction schedule (French, 1996). For example, construction element such as R.C column is given the "*ID as COL_235*" in the as-planned schedule via Primavera P6; accordingly, the same column should be assigned with the same code in the field book for easy identifications to reduce the chances of making errors.

The output for this process is a classified and identified coded data recorded manually, either in a document or computer linking each element collected from the site with its corresponding element in the construction schedule in a more organised fashion. Hence, the refined data is organised in groups, for example, concrete columns are grouped together and similarly walls, beams, etc.

"Preparation of data for input": this process involves sorting and rearranging the processed data from the previous step and sorting it, for example, according to the floor level (for buildings), and therefore, concrete columns, beams, walls for first floor are sorted together and similarly for second floor, etc.

The main objective for this stage is to verify and ensure the accuracy and sufficiency of the collected data, in other words, the data feeders will be able to recognise whether the collected data is enough for analysis or whether additional data needs to be collected. In case the collected data is not enough, inspectors revert back to site to collect the missed data. According to Gloparvar-Fard *et al.,* (2011) missing data during manual data collection is common in construction projects.

Cheng and Teizer (2013) considers data integration as accomplishing its aim only when the output of this processed data is complete and sufficient for further analysis. According to French (1996), manual integration of data involves one of the following two processes, the first is totally manually and the second is sometimes with the aid of a computer.

The only tools required for the first manual process are paper and pen, where the **input** is the coded data, and the **output** is spreadsheets entailing of the as-built details in a form of quantified numbers, percentage, areas, and volumes.

However, the tool for the second computer aided process is a computer and the **input** likewise, is the coded data that is entered manually and the **output** is a digital spreadsheet encompassing the organised collected as-built data in a form of quantified numbers, percentage, areas, and volumes.

Indeed, the widespread and versatile use of computers has hastened demise of manual processing. Accordingly, it is seldom to find nowadays manual data processing, especially for big data (French, 1996; Sidawi and Al-Sudairi, 2013).

Ultimately, data integration and preparation of the processed data will need to be ready for entry in the next process, to enable the planning engineers to analyse the data to determine the progress status and detect the delays.

2.4.2.1 Limitations of manual data integration and preparation

It is clear this process encompasses two sub-processes which essentially require human intervention and therefore, data entry is prone to errors, time consuming and accuracy of the data entered uncertain, mainly because it depends on the attentiveness of the data feeders.

2.4.3 Data analysis

Data analysis is the final process in the preparation stage to developing meaningful information as a ready input into the progress report to update and support decision makers (French, 1996; Keim *et al.,* 2008). After thorough research and further review of pertinent literature, it is found that there is no specific definition for data analysis, that has been developed predominantly for construction projects. However, the most relevant definition is articulated by Keim *et al.,* (2008) as follows, “data analysis can be defined as the process that involves comparing the as-planned schedule against the data collected for the real life as-built to figure out the progress status and delays”.

Conversely, data analysis is also known as data mining or knowledge discovery. However, the data mining term is usually used for large amounts of data which requires computer software, machine learning, add-in algorithms and complex methods to analyse this type of data (Ester *et al.,* 2000; Maimon and Rokach, 2005).

Briefly, the main goal for this process is to realise the project performance to find out the project status (i.e. delayed, on schedule or ahead of the planned construction schedule) by comparing the as-built against as-planned schedule.

Data analysis follows either one of two methods, manual analysis in particular for small projects or computer based-software analysis which is the most common method (Aigner *et al.,* 2008). In fact, manual data analysis relies basically on mathematical equations and arithmetic calculations using tools such as paper, pen and calculator. However, computers equipped with commercial software accelerate the processes to enable recognition of the project status in few minutes. Practically, the computer based-software analysis method requires manual feeding of the data.

The literature study revealed several criterions are tracked to assess the construction project performance such as *time, cost, quality, safety, disputes and client satisfactions* (Hill, 2008; Bhargava *et al.,* 2010; Anastasopoulos *et al.,* 2012; Cakmak and Cakmak, 2014 Arantes *et al.,* 2015).

However, there is a great deal of consensus among researchers and the construction industry professionals that on time and cost are the best measures to estimate the construction performance (Meredith and Mantel, 2006; Toor and Ogunlana, 2010; Adam *et al*., 2015; Aryal and Dahal, 2018).

Many researchers have proposed measuring the construction progress by comparing the actual progress against the planned construction schedule considering time as the Key Performance Indicator (KPI). According to Toor and Ogunlana (2010) time is the main criterion for assessing construction progress and due to its intrinsic correlation with cost accordingly, determining the construction duration enables easy and accurate estimation of the correlated expenses. Actually, there are numerous researchers have used the time as the main measure to determine the progress status and the construction performance such as (Leung et al.,2008; Ibrahim *et al.,* 2009; Gloparvar-Fard *et al.*, 2009; El-Omari and Moselhi, 2011; Dimitrov and Gloparvar-Fard, 2014; Omar *et al.,* 2018).

The literature review demonstrated several methods for estimating the progress status, however, the most and widely used methods are Gantt charts, Earned Value (EV) and 4D BIM.

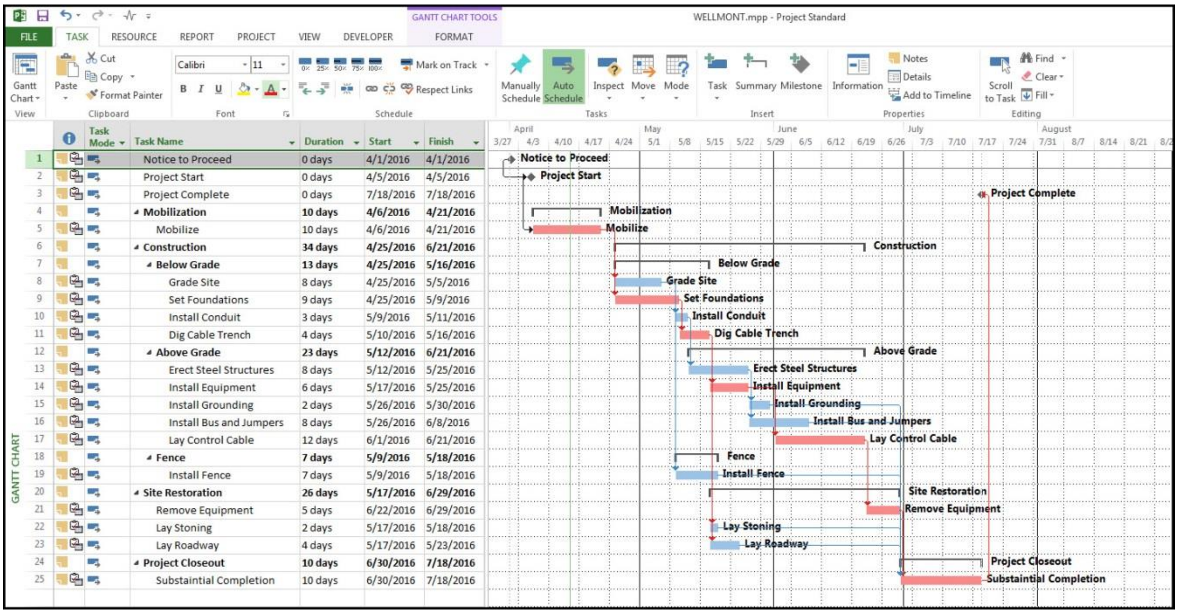
2.4.3.1 Gantt chart

It has been established that the Gantt chart is not only recognised as one of the oldest but also still one of the most significant analysis methods used to assess the construction performance. The Gantt chart is used to determine the construction progress status by comparing the actual progress status against the planned progress to calculate delays.

In 1903 a primitive version of Gantt chart was proposed by a pioneer in scientific management called Henry L. Gantt within his research titled "*A graphical daily balance in manufacture".* During World War One in 1917, Gantt developed the professional version of Gantt chart, and subsequently, the Gantt Chart became popular and used widely in the mid-1920s (Wilson, 2003; Meredith and Mantel, 2006; Weaver, 2012).

Typically, a Gantt chart shows the project tasks on the horizontal bars, with each bar representing a task with its unique ID and name in a time scale with start and finish dates i.e. Early Start (ES) and Late Start (LS), Early Finish (EF) and Late Finish (LF). The following Figure 2.3 shows a sample of Gantt chart.

The first versions of Gantt charts used to be developed manually, however, with advancements in computer software it is now developed in Microsoft Excel for simple and small projects. However, for the larger and more complex projects that encompass many tasks there are several options for commercial software available off the shelf and the most well-known and largely used of them are Microsoft Project, MindView and Oracle Primavera (Maylor, 2001; Wilson, 2003).



Source: www.Tensix.com , used with permission from Emily Foster@ Ten Six Consulting

Figure 2.3: Sample of Gant chart showing project activities

Gantt charts are used on a wide scale enabling comparison between the as-planned schedule and the actual data collected from the site allowing analysis of the construction performance. The progress of each activity is demonstrated as a shaded bar reflecting the progress in percentage (Pathak, 2015).

The following Figure 2.4 shows the construction performance for each activity as on 30th April 2016.

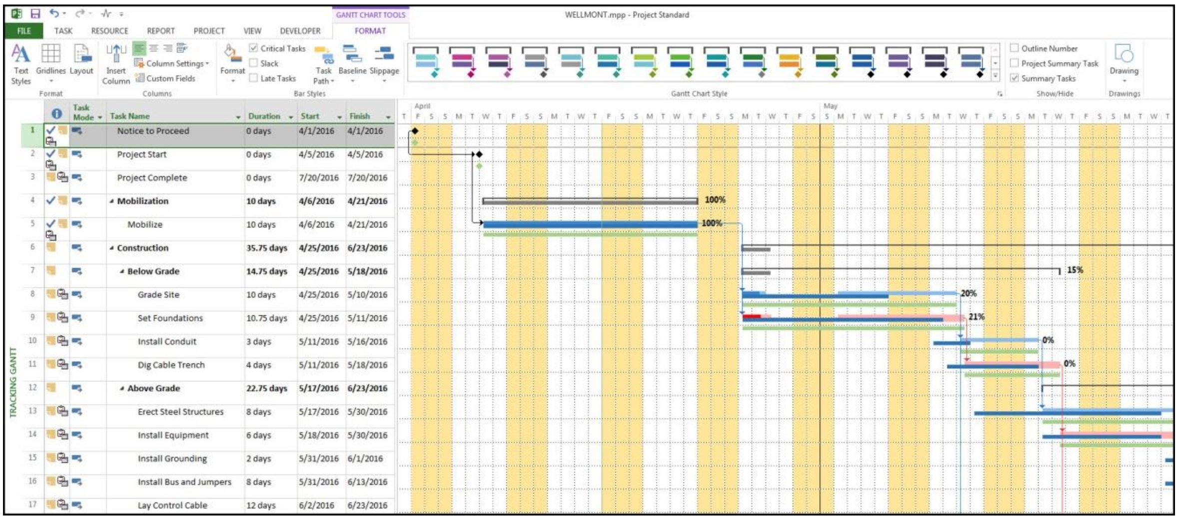


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Figure 2.4: Gantt chart shows status for each activity

A great deal of consensus has been reached amongst researchers about the distinctive features that the Gantt chart method has assimilated, as follows (Maylor, 2001; Wilson, 2003; Weaver, 2012; Nurre and Weir, 2017).

1. It is distinguished by its simplicity and ease of use.
2. It does not require much time to prepare the baseline program.
3. Resources can be easily integrated into the baseline program.
4. It is easy to update the baseline program during the construction project.
5. Progress summary can be easily extracted and visualised on a bar chart.
6. Progress status can be determined based on the data collected from the site at anytime.
7. The progress status for each activity and the overall project is shown as a percentage. Accordingly, delays can be easily identified.

According to Meredith and Mantel (2006) the Gantt chart has some shortcomings outlined as follows:

1. The Gantt chart method is not the most appropriate method for sophisticated projects with a large number of tasks as it becomes too complex and difficult to understand.
2. A dedicated specialised planning engineer is required for the project.
3. To calculate the progress status, manual inputting of the collected data from the site is required either daily or weekly. Accordingly, accuracy of progress status heavily relies on the accuracy of the collected and the feeding process.
4. Typically visual representation for the progress status cannot be presented on one page as the project encompasses numerous activities.
5. There are additional associated costs with software licenses needing to be puchased such as Primavera or MS project.
6. Despite some activities having the same duration to completion; they often have a different weighting for example, an expensive 4000 kW diesel generator will be installed typically in 3 days and usually requires heavy cranes, a long vehicle and a large number of labour and specialised staff. Conversely, painting one wall in a room requires only cheap materials and tools in addition to only one labourer but will be completed in the same duration, that is, 3 days.

   The Gantt chart does not have the ability to distinguish the weightings of the activities because it mainly focuses on the completion duration for each activity.

Indeed, the last limitation on its own justifies the reason for not adopting the Gantt chart as the main approach for automating the process of monitoring and controlling construction projects.

2.4.3.2 Earned Value Management (EVM)

Several authors have claimed the concept of EVM is not new and its roots can be traced back in the late 1800s (Fleming and Koppelman, 2000; Kim, 2000; Anbari, 2003). However, EVM was introduced by the US federal government around 1967 as an integral part of its cost and schedule control system (Anbari, 2003). Construction project owners witnessed tangible improvements and better control of projects that adopted EVM. The US federal government has broadly thereof used EVM in its projects and by the end of 1996 the US federal government decided to discard its Cost/Schedule Control Systems Criteria (C/SCSC) and replace it with EVM (Anbari, 2003; Meredith and Mantel, 2006). Since then, the high degree of acceptance in using EVM makes it the most commonly used method for cost and schedule control to evaluate project progress and performance (El-Omari and Moselhi, 2011; Sumara and Goodpasture, 1996, PMBOK, 2017).

PMBOK (2017, p.216) defined EVM as *"a methodology that combines scope, schedule, and resource measurements to assess project performance and progress"*.
Several authors have affirmed that EVM is an effective technique for measuring the project performance, whereas EVM integrates project baseline scope, cost and schedule as the reference against what the project status can be assessed (Anbari, 2003; Marshall, 2007; Czemplik, 2014; Chen *et al.,* 2016; PMBOK, 2017).

EVM enables project managers to monitor the project performance using three key measures for any industry which are, scope i.e. the tasks that must be implemented to deliver the project and compares the scope against its planned schedule and cost (PMBOK, 2017).

EVM basically has three main metrics which are described below, based on PMBOK, (2017):

Planned Value (PV): PV is the planned budget for the project distributed along the project lifetime and represented with a shape similar to the letter *S*, sometimes known as the "*S curve,*" and at the date of project completion it is called as Budget At Completion (BAC).

Earned Value (EV): EV is a term used to describe the completion percentage of a project together with its incurred budget. Project managers monitor EV, both incrementally to determine current status and cumulatively to determine the long-term performance trends.

Accordingly, EV measured cannot be greater than the authorised PV budget for a component.

Actual Cost (AC): AC is the total cost that has actually been incurred and recorded in accomplishing work performed for an activity during a specific time period. It is the total cost incurred for accomplishing the work that the EV measured. The AC will have no upper limit and whatever is spent to achieve the EV will be measured.

Variances from the approved baseline are also monitored and expressed in the following terms:

Schedule Variance (SV): SV is a measure of scheduled performance expressed as the difference between the earned value and the planned value. It is the amount that the project performance compares with the project baseline, to show the project performance, whether this falls behind or ahead of the planned delivery date.

$SV = EV - PV$……………….. (1)

Cost Variance (CV): CV is the amount of budget deficit or surplus at a given point in time, expressed as the cost performance on a project compared with the planned value and BAC. CV for the project at the completion will be the difference between the budget at completion (BAC) and the actual cost spent to complete the project. The CV is critical because it indicates the relationship of physical performance to the costs spent. Negative CV is often difficult for the project to recover.

$CV = EV - AC$………………. (2)

Schedule performance Index (SPI): SPI reflects the progress achieved compared with the planned progress; if the SPI value is less than 1 the completed works are less than the planned works which means the project has fallen behind schedule. However, if SPI is greater than 1 it means the completed works are more than the planned works and the project progress is ahead of its planned schedule. If SPI is equal to 1 that means the project is progressing according to the plan without any deviation. SPI expressed in ratio as follows;

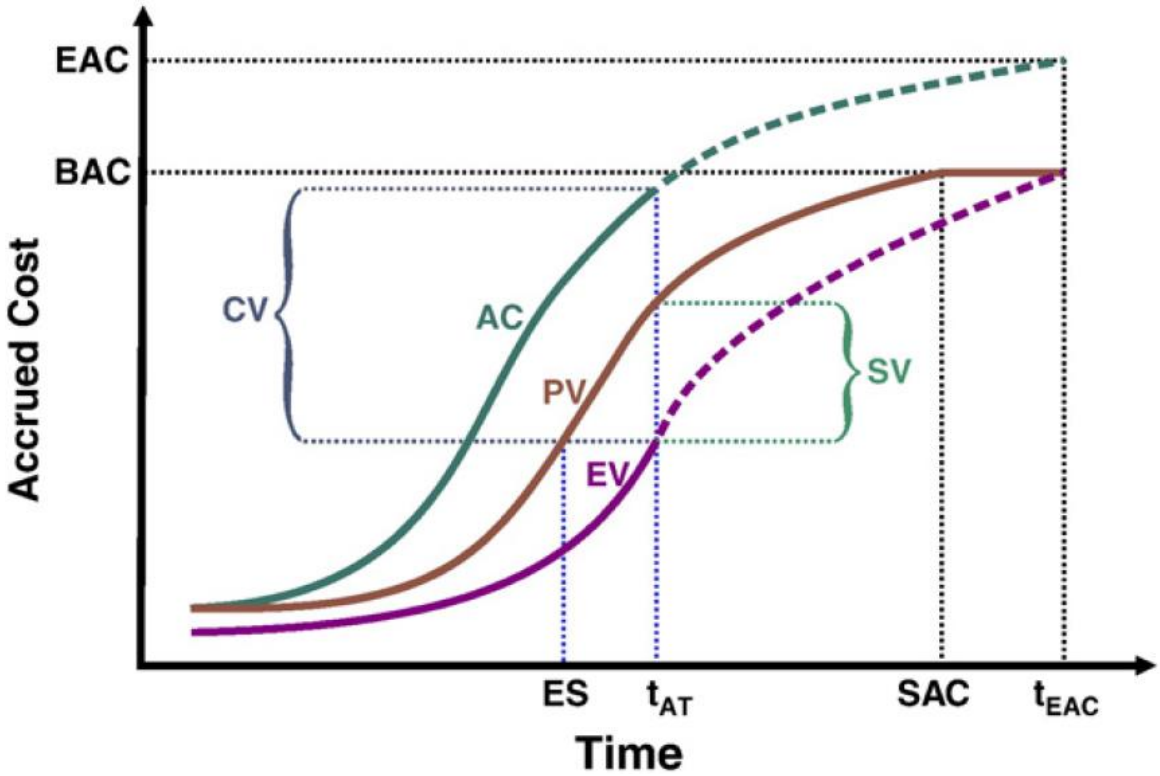
$SPI = EV \div PV$…………….. (3)

Cost Performance Index (CPI): CPI is a measure of the cost efficiency of the budgeted resources and meansures the completed works against the actual cost or progress made in the project. It is considered the most critical EVM metric and measures the cost efficiency for the work completed. If CPI value is less than 1 that means cost overruns for the completed works. In the case of CPI being greater than 1 this indicates the spent budget is less than the plan. CPI expressed in ration as follows;

$CPI = EV \div AC$…………….. (4)

The project performance is traditionally monitored using the abovementioned metrics on a weekly or monthly basis and cumulative basis.

The following Figure 2.5 uses the S-curves to display EV data for a project that is performing over budget and behind the schedule.



Source: Pajares and López-Paredes (2011), used with permission from Javier Pajares

Figure 2.5: EV, PV and AC

The features of EVM, result in better control being accomplished for the construction project (Chen *et al.,* 2016). It is obvious EVM is an effective measure to determine project performance; it has the ability to forcast the project completion date and budget at completion.

EVM metrics are either calculated manually or through dedicated software such as Microsoft Project, Oracle's Primavera P6, Deltek Open Plan or Artemis software.

The use of EVM is not limited just to construction projects, its use extends to include other industries such as manufacturing, mining, fishing, forestry, agriculture, etc. As such, EVM is considered as one of the widely used techniques in assisting decision makers to monitor the performance of their projects (Meredith and Mantel, 2006; Ong *et al.,* 2016). Moreover, EVM is an effective technique used for all sizes of projects, ranging from simple, small to big and complex (Turkan *et al.,* 2013; Chen *et al.,* 2016).

Outlined below are the most distingushed advantages recognised for EVM as cited by several authors (Czemplik, 2014; Guo *et al.,* 2016; Chen *et al.,* 2016; Zohoori *et al.,* 2019).

1. It is suitable for all projects regardless of its nature, complexity or size.
2. The three metrics of EVM (i.e. PV, EV and AC) give a clear picture the project performance.
3. EVM enables calculation of the three metrics for each activity independently and collectively and holistically for the project.
4. EVM improves the certainty of project’s delivery date and the final cost.

Despite its wide use and tangible efficiency that enables decision makers to have better control on their projects, EVM suffers from some limitations as mentioned hereinafter.

1. The main premise of EVM is synchonisation of the time and cost metrics together, therefore, it is not suitable for the projects that do not have the detailed scope of works corresponding each construction element to its cost (Pajares and López-Paredes, 2011).
2. Cost metrics are often misleading and its reflection on the S-curve is not accurate; the S-Curve only shows the actual costs for the work done/completed activities. Although, some expenses are incurred in advance, they are not considered in the S-curve becuase those activities are not as yet completed, for example, down payments for purchasing materials or services required to complete the whole project to be reflected on the S curve (Lukas, 2008).
3. One of the reported weaknesses of EVM is the ability of management or human influence in changing and manipulating the EVM results, which can result in misleading the project owner and stakeholders. This usually occurs because the contractor’s target for the quarter “must” be met, or the human behaviour of avoiding delivering bad news, that is the project falling behind the plan and exceeding the planned expenditures (Lukas, 2008).
4. To update the progress status, EVM requires manual data entry, and accordingly the accuracy of the outputs are intrinsically linked with the accuracy of the manual inputs. For example, if the data fed to EVM equations are inaccurate, consequently, the outputs pertaining to the project performance will mislead the project manager (Gua *et al.,* 2016).
5. EVM lacks the ability to distinguish the activities that do not impact the project success and those might put the project at risk (Wang *et al.,* 2006).
6. Purchasing a software license and recruiting a dedicated planning specialist are required costs to feed in the data and interpret the results (Czemplik, 2014).

7. Due to a heavy reliance on manual inputs, misleading outputs tend to be the inevitable result (Aliverd *et al.,* 2013).

The aforementioned limitations justify why some project managers are adverse to using EVM, as the main method of automating the process of monitoring and controlling construction projects.

Accordingly, a more flexible approach is preferred and with the advent of BIM, 4D BIM model seen as the panacea.

2.4.3.3 4D BIM

BIM is a revolutionary technology and management tool that involves the development and use of "a computer software model to simulate the construction and operation of a facility". The resulting model is a data-rich, object-oriented, intelligent and parametric digital representation of the facility, from which views and data are appropriated and analysed to generate information that can be used to make decisions and improve the process of delivering the facility (AGCA, 2005; Linderoth, 2010; Jernigan, 2014). Eastman *et al.,* (2011) claimed that, the use of BIM produced error-free design which boosted offsite prefabrication. Accordingly, BIM was the most popular system and most utilised in the last two decades within the construction industry.

Study of the literature shows that there is concrete evidence of serious attempts to create BIM since the 1960s; the most renowned endeavour was recorded by "Douglas Engelbart" in 1962 in his published paper titled "*Augmenting Human Intellect*". Douglas suggested the principle of object-based design which was later considered as the primitive rubric for the BIM model (Bergin, 2011). In 1975, Charles Eastman published a paper titled "*Use of Computers Instead of Drawings in Building Design*" of which he described the 3D model as a single integrated database used for analysis (Bergin, 2011). Eastman's paper paved the way for further studies and developments of computer programs, and as a result of these endeavours, in 1984 first 3D model developed by Graphisoft.

The competitive rivalry among software developers and researchers created a breakthrough for BIM, whereby in 2000 Autodesk developed Revit used for creating 3D models, and then in 2001 they developed Navisworks which is used for creating 4D models (Bergin, 2011).

- **3D BIM Model** is defined as an object-oriented model embracing all the information required to visualise and simulate the project for virtual mimicing of its details prior to construction (Azhar *et al.,* 2012; Abbasnejad and Moud, 2013).

- **4D BIM model** is a planning and scheduling tool that integrates 3D BIM model with construction activities to assist project participants visualising effectively the construction sequences and analyse the project performance (Dawood and Sikka, 2008).

There is a wide range of professional 4D BIM software such as Vico Office from Trimble, Synchro Professional from Bentley, Navisworks from Autodesk, Kreo from Kreo, and iTWO from RIB.

The aforementioned analysis approaches i.e. Gantt chart and EVM require the power of imagination for all what will need to be constructed based on the 2D drawings (i.e. as-planned schedule). As the imagination varies from one to another, it imposes an extra burden on the site staff to memorise the construction sequences (Fischer *et al.,* 2003; Ciribini *et al.,* 2016).

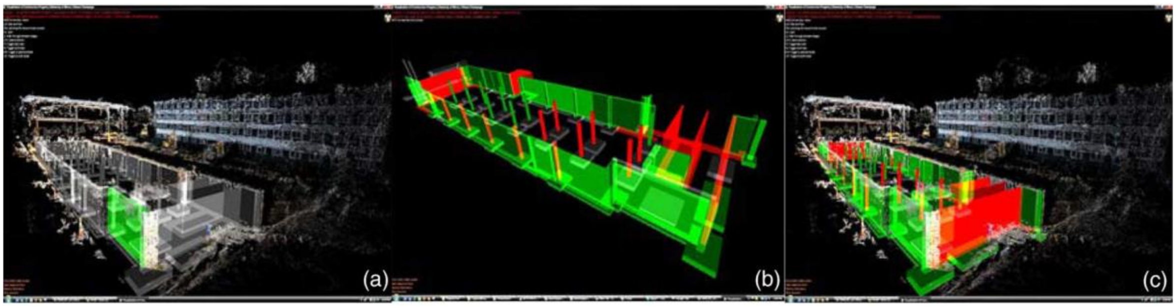
With thanks to the 4D BIM model, the project schedule together with all construction sequences can be virtually visualised prior to starting site activities (Leich and Messner, 2008; GSA BIM guide series, 2009; Azhar, 2011; Ciribini *et al.,* 2016).

The fundamental prerequisite of acquiring reliable analysis fom the 4D BIM's data, is corresponding and synchronising the 3D and 4D models, which necessitates decisions on the construction sequences. Obviously, the development of 3D significantly affects the development of 4D BIM model (Eastman *et al.,* 2011; Ciribini *et al.,* 2016).

Typically there are two ways to develop a 4D BIM model with the first being the most used especially for projects with many activities. Scheduling software such as Primavera P6 is exported into 4D software such as Navisworks from Autodesk or Synchro from Bentley or any other 4D tool. The compatibility between the 3D and 4D models enables automatic synchronisation of the inserted details. Furthermore, any changes or updates including additions or omissions in the 3D model will automatically change or update the 4D model.

The second way is by manual insertion of each and every activity into the 4D software, by inputting the activity ID, activity description, start and end dates, each float, the logical links between the activities and resource allocations. In both cases, the baseline schedule that is developed prior to starting the construction represents the as-planned schedule.

To analyse the data collected from the site, data is typically inserted manually into the 4D model to visualise and calculate the project status according to the given colour coding. Figure 2.6 shows the delayed activities in red and ahead activities in green (Golparvar-Fard *et al.,* 2010).

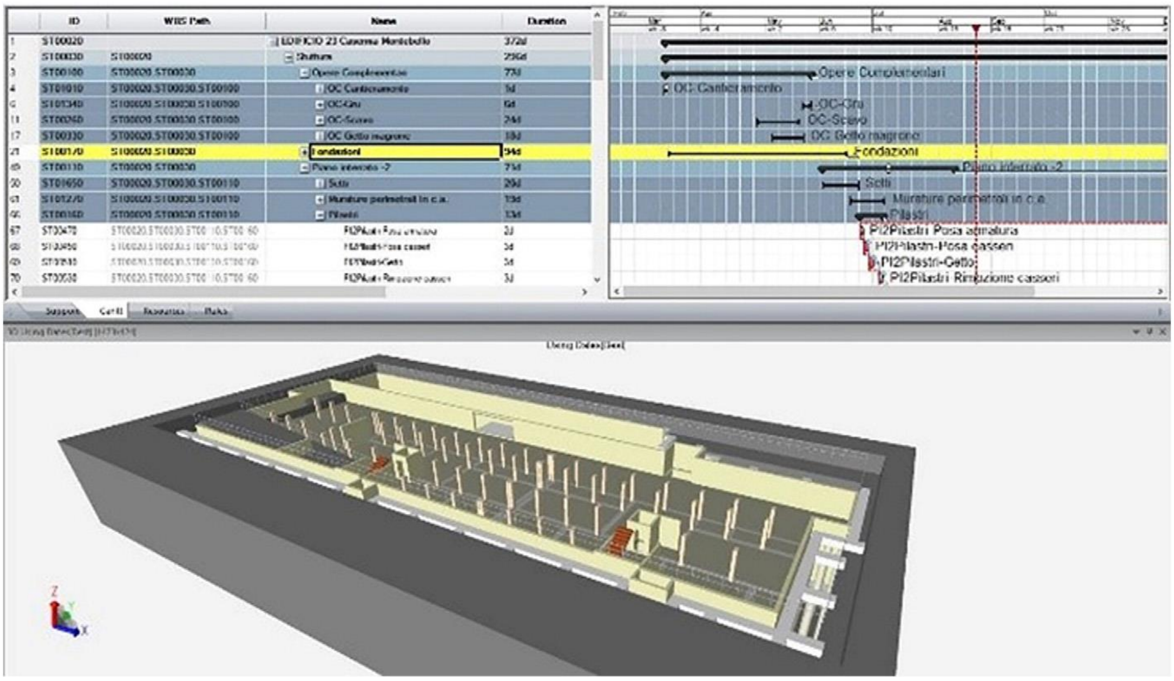


Source: Golparvar-Fard et al., (2010), reused with permission from Golparvar-Fard

Figure 2.6: Progress status in colour codes, red means delayed, and green is ahead

In addition to the abovementioned two ways, Ciribini *et al.,* (2016) in their case study utilised 4D BIM as a reliable analysis tool to monitor the construction progress status, wherein they have used Allplan to create 3D BIM model and Synchro pro to develop 4D BIM model. To ensure auto-checking they exported to an excel sheet the 3D BIM parametrs, activity name and ID for each object, and at the same time they exported the construction schedule from Synchro pro to the Excel sheet. Next they manually synchronised the activities from both sources to ensure conformity between the 3D and 4D schedule. Finally, the synchronised data was imported back into Synchro Pro. The followingSource: Ciribini *et al., (2016, p. 71), used with permission from Elsevier*

Figure 2.7 shows the visualisation of the construction progress using Synchro Pro.



Source: Ciribini et al., (2016, p. 71), used with permission from Elsevier

Figure 2.7: Visualisation of the construction schedule in Synchro Pro

It is clear that 4D BIM has resolved several problems that were previously considered unresolvable within the traditional analysis approaches. According to Kymmell (2008) visualisation of the building is one of the greatest values added to the construction industry which has enabled a clear interpretation of construction progress. Moreover, after manual insertion of the data collected from the construction site, 4D has the potential to analyse the progress rapidly and accurately compared with the traditional approaches.

Despite the promising properties that encapsulated in 4D BIM as a distinctive analysis tool, the following limitations are reported:

1. The 4D model cannot determine explicitly the project's overall progress in percentage terms, as it requires abstracting this information from synchronised scheduling software such as Primavera 6 or MS project. Typically, the 4D model is automatically linked to Primavera P6 or MS project to reflect any updates on the schedule to the 4D model and to update the overall progress status (Eastman *et al.,* 2011; Hardin, 2014).
2. Human intervention is fundmental in the collection of data and the input of data into the 4D BIM model is still a manual process . Accordingly, the accuracy of the progress status is relative to the accuracy of the collected and inputted data (Eastman *et al.,* 2011).
3. Manual feeding of the data into the 4D is time consuming and prone to errors (Turkan *et al.,* 2012; Boton *et al.,* 2015; Jupp *et al*., 2017).

The 4D BIM model has distinctive features, specifically the automatic synchonisation with 3D BIM model which makes it the most widely used approach for the current endeavors in automating the process of monitoring and controlling construction projects.

2.5 Reporting

In order to ensure effective monitoring and controlling of construction projects, the owner instructs the main contractor to prepare and submit weekly, fortnight or monthly construction progression reports. To that end, the main contractor will collect daily progress reports from his subcontractors and staff which are usually in a paper format (Hendrickson and Au, 1998; Roh *et al,* 2011). Noticeably, every organisation follows its own format for progress reporting. However, regardless of the format, progress reports have to include certain fixed information without which the report is deemed incomplete and meaningless. Commonly, staff write monthly progress reports to keep the management and the decision makers informed about the accomplished progress.

According to Cambridge Dictionary (2008), a *progress report* is defined as "a written document that explains how much progress is being made on something you have previously planned".

The aim of reporting the construction progress is to inform the client, project manager and decision makers about the progress made over a period of time to establish whether project objectives have been achieved. Additionally, its aim is to recognise what are the encountered problems, outlays and to pinpoint delays that affect the planned completion date (Project reporting, 2015). Obviously, progress reporting is a fundamental management tool which must be continuously updated as it is the main information source and the basis of which the project manager and stakeholders are making decisions to ensure the project is completed on time and on budget in accordance with the plan.

Typically, construction reports are prepared by the main contractor on a monthly or fortnightly basis; however, for critical projects construction reports are prepared weekly. Indeed, the frequency of reporting should be enough to enable the project team to have a better control and management of the project (Meredith and Mantel, 2006; Zhang *et al.,* 2009).

To recognise the project performance from reports, the actual work done (the as-built) should be compared against the as-planned shedule. These comparisons are usually reported in the form of tables, pie or bar charts and reports that provide critical information of expenditure and the schedule status to support more informed decision making for those responsible with better monitoring and control of the project (Zhang *et al.,* 2009; Roh *et al*, 2011).

According to GenieBelt (2019) there are two main types of construction reports. The first type usually is addressed to senior management, wherein the report should encompass a project overview describing the progress as a summary with less detail. However, to enable appropriate actions from senior managers, a more detailed report is required.

The second type of reports are addressed to operational management and these reports usually involve the progress status for each activity in detail.

Weekly and/or monthly construction reports are important documents for all of the project decision makers which should encompass at the very least the following details.

1. An executive summary of the project.
2. A comparison between the as-built and the as-planned shedule, showing the critical, delayed and ahead activities.
3. A projected plan for the next two weeks.

4. Justifications for any causes of delays.
5. Photos of the site progress.
6. Weather report.
7. QA/QC report.
8. Health, Safety and Environment (HSE) report.
9. Cash-in/Cash-out illustration.
10. Histograms of resources (human, machines and equipment).
11. List of materials and delivery plan.
12. A detailed list of the required actions, including responsbility and when to be taken.
13. List of near critical activities and the course of actions to be taken to avoid delays.
14. Mitigation plan to alleviate the occurred delays.
15. List of claims with justifications.

It is evident that the construction report is a crucial document prepared for the client by the main contractor to demonstrate project performance. Meredith and Mantel (2006) outlined the benefits of progress reports for project stakeholders as following:

1. Progress report avails a mutual understanding of the project objectives.
2. Shows progress status and activities for the Work In Progress (WIP) and any associated problems.
3. Enables a more realistic plan in accordance with project resources.
4. Gives early warning signals of potential problems and delays in the project.
5. Enables a swift response from the project management team to respond to any potential delays or unwanted deviation from the plans.
6. Keeping the client and other stakeholders updated and informed of project performance.

Meredith and Mantel (2006) also claimed that, traditional reporting suffer from some glitches such as:

1. Reports are usually too detailed and tedious to read reducing the liklehood of them being read.
2. Reports tend to contain repetitive content which can result in a psychological barrier for the reader to continue reading the report.
3. Typically, reports include a myriad of information which lead to a lack of interest in the preparation of the reports. losing interest for preparing the reports. Consequently, it casts doubts on the validity and reliability of the information included in the report.

4. Traditionally, updating the progress status is a slow process, wherein preparation of the progress report heavily relies on the manual preparation, integration and preparation of the data, and analysis which makes it a lengthy process and potentially lacks credibility (Koo *et al.,* 2000).

   Thereto, the duration required to prepare the report for progress update is between four and seven days, and in some cases may take longer, particularly for projects with a multitude of activities (Morad and Beliveau, 1991). This lengthy duration of preparation adversely impacts the reliability and accuracy of the report. For example, data collected from site on 1st June 2019 whereby the report will be ready for the project manager to make their decsions on 8th June 2019. This means the project manager's decision will overlook any issues that occurred between 2nd June 2019 and date of the next progress report. Consequently, decisions are taken for obsolete events/delays. Those overlooked events/delays that are not included in the progress report often have more impact on the project than those that are reported (Meredith and Mantel, 2006).
5. The Construction Industry Institute (1997) adduced that, expenditures required for tracking, updating and reporting construction site activities, cost between US $500,000 to US $1 million for construction projects with budget US $100 milion.
6. Moreover, Cheok *et al.*, (2000) established that, 2% of the project budget is lost in manual tracking and reporting of work progress.

It is clear that, the current manual approach used for updating, monitoring and controlling construction projects suffers from myriad of limitations that impede its efficiency. Therefore, the adoption of technology should result in a decrease of wasteful efforts and time, in addition to boosting accuracy and reliability enabling a reduction of delays in construction projects.

Accordingly, several attempts have been made to resolve the salient challenges associated with limitations of current manual monitoring and controlling systems. Consequently, a great deal of work has been devoted to developing monitoring technologies. Chapter 3 will introduce these developments which could be classified as standalone and integrated technologies.

2.6 Chapter summary

Although the construction industry is a significant contributor to the national GDP globally, it is astonishing that construction projects tend to suffer so much from time delays. These delays are associated with a failure to deal with loose control of projects, which are often brought about by poor project management strategies and outdated monitoring methods.

There is a critical need to detect delays which has been stressed over several decades, and thus, controlling project timescales and costs are an overriding concern for the entire project supply chain including client and contractors alike. The literature review provided concrete evidence of the inadequacy and weaknesses of the existing dominant approaches for monitoring and controlling delays and are outlined as labour intensive, time consuming, prone to errors, inaccurate and unreliable.

Over the last few decades, a great deal of work has sought to improve the manual approaches for monitoring and updating construction progress. In the same context, early efforts sought to find solutions by utilising the technologies to automate the processes of monitoring and controlling construction site activities.

Chapter 3-Approaches, techniques and technologies to address project overrun

3 Introduction

The main objective of this chapter is to provide a comprehensive review of the existing literature to understand state-of-the-art for current monitoring and updating of systems with a special focus on limitations, advantages and the technology employed for each system.

These systems are classified into two main categories, standalone technology and integrated technologies. Accordingly, this chapter is divided into two sections, standalone technologies are introduced in the first section and the second section introduces integrated technologies. Each section puts forward a diversified range of technologies which are presented chronologically. Prior to introducing these proposed systems which endeavour to address delays in construction projects, a historical overview of employed technology is provided including necessary definitions. The architecture and benefits of the proposed systems are thoroughly researched and critiqued to recognise their limitations.

The following Figure 3.1 outlines the structure of this chapter. The first section introduces three standalone technology systems - the first being Virtual Reality (VR) technology, the second system that utilises a time-lapse technique and the last system which employs Computer Vision (CV). Whilst, six systems of integrated technology are discussed, the first system that employs photogrammetry, Laser Scanning and the 3D point cloud model; whilst the second utilises Photogrammetry, LS, 3D point cloud and BIM, the third Photogrammetry, CV and BIM, the fourth Photogrammetry, CV, BIM via walkthrough, the fifth Satellite, GIS and BIM, and finally the sixth system that uses photogrammetry, Machine Learning (ML), BIM and 3D point cloud.

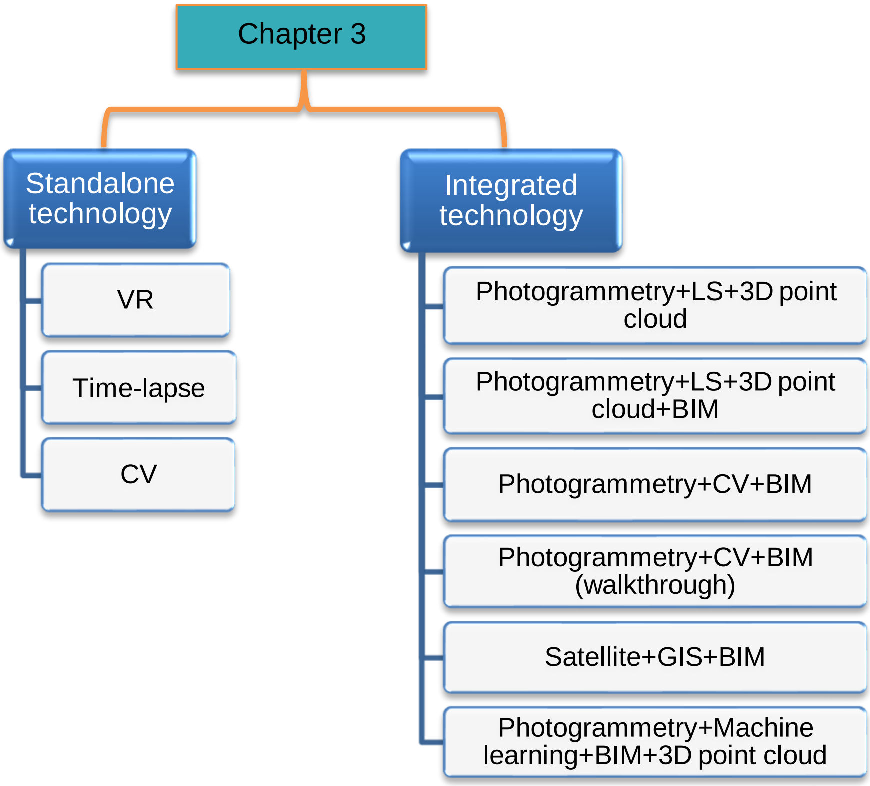


Figure 3.1: Structure of chapter 3

3.1 Current and emerging site monitoring and controlling systems for detection of project delays

Several attempts were made to resolve the salient challenges associated with limitations of current monitoring and controlling systems. Consequently, a great deal of work has been devoted in developing monitoring technologies. Broadly speaking, these developments could be classified as either standalone or integrated technologies.

Standalone technology: This system utilises only one technology for all its different processes (data acquisition, integration and preparation, analysis and reporting) (Navon 2000).

Integrated technology: This system employs a mix of two, three or more integrated technologies.

After a thorough study for the current literature, it was found that the most commonly used technologies for standalone and integrated systems are of the time-lapse technique - Global Information System (GIS), Computer Vision (CV) technology, Virtual reality (VR),

Photogrammetry, Laser Scanning (LS), Machine Learning (ML) and BIM (Burke *et al*., 2003a ; Sonmez and Uysal, 2008; Taylor *et al.,* 2009; Bosché, 2010; Ness *et al.,* 2014; Kopsida *et al.,* 2015; Omar and Nehdi, 2016; Wu *et al.,* 2017).
The following section introduces several systems that utilise different technologies in an attempt to automate monitoring and controlling processes for construction projects.

3.2 Standalone technology

Standalone system is a system whereby only one technology is used to automate the manual processes of tracking construction progress. Pursuant to the records of the available literature, there were some attempts before 1990s aimed at automating construction progress updates. However, the momentous research contribution in this field was achieved by late 1990s.

In 1999, Retik and Shapira proposed a system that sought to assist the site staff in recognising the status of construction progress. To that end, they utilised ***VR technology*** to enable simulation and visualisation of work progress.

3.2.1 Virtual Reality (VR)

3.2.1.1 Historical glimpse for VR

The VR roots can be tracked back to late 1950s when Morton Heilig the American cinematographer who is known as "*the father of VR"*, invented the first VR machine in 1957. This machine is so called "Sensorama" a multimedia machine that enabled users to visualise the images within a 3D environment and enjoy an interactive experience (Merchant *et al*., 2014).
In 1961, Charles Comeau and James Bryan created the first ever head mounted VR display device, followed by Thomas Furness' development in 1968 who enabled simulation of air force flights using VR technology (Carmen, 1992). In the same year, Ivan Sutherland a Harvard Professor and computer scientist together with his student Bob Sproull invented the first head mounted VR/AR and named it "*The Sword of Damocles.*" Sutherland's invention made a paradigm-shift in VR technology, whereby 1980s and 1990s witnessed a great deal of developments for the VR technology (Steinicke, 2016).
Jaron Laniers' relentless efforts resulted in VR being publicised in 1985 when he developed the first commercial version of VR Google which attracted a great deal of attention from researchers (Steinicke, 2016). The literature search revealed numerous records of abundant endeavours throughout the tenure of the 1990s which ultimately contributed to the current significant advancements of VR technology.
According to Steinicke (2016) in the years 2000 to 2015, saw exceptional advancements in VR technology. However, 2016 was considered the year of VR, wherein Palmer Luckey

developed the first Oculus VR system which triggered competition amongst several giant companies in the development of VR technology. Thanks to these companies such as Sony, Facebook, Google, Microsoft and Samsung, the use of VR technology was populated and commercialised in almost every aspect of life (Steinicke, 2016). Nowadays, the use of VR is not limited to the construction industry; it is commonly found in a wide range of industries with multiple uses, for example surgical training (Kardong-Edgren *et al.,* 2019), tourism (Kaminski, 2017), home furniture (Buttussi and Chittaro 2018), military training (Hill *et al*., 2001), firefighting training (Cha *et al.,* 2012), education (Merchant *et al.,* 2014) and others.

3.2.1.2 Definition of VR

There are many definitions of VR with Coates (1992) defining VR as "*electronic simulations of environments experienced via head-mounted eye goggles and wired clothing enabling the end user to interact in realistic three-dimensional situations*". Likewise, Steuer (1995) formulated his definition for the VR as a set of technological devices including a computer and head mounted goggle equipped sensors.

According to Schroeder (1996) VR is *"a computer-generated display that allows or compels the users to have a sense of being present in an environment other than the one they are actually in and to interact with that environment".* In the same context, McCloy and Stone (2001) defined VR as "*a collection of technologies that allow people to interact efficiently with 3D computerised databases in real time using their natural senses and skills*".

The following research is a clear example of the successful utilisation of VR in the construction industry as a standalone technology, whereas Retik and Shapira (1999) sought to automate the assessment of construction progress as detailed hereinafter.

3.3 Research title: VR-based planning of construction site activities

The systems' main premise was to develop realistic 3D view from the vast number of captured 2D photos of the on-site construction progress, allowing site staff to visualise the progress in 3D views.

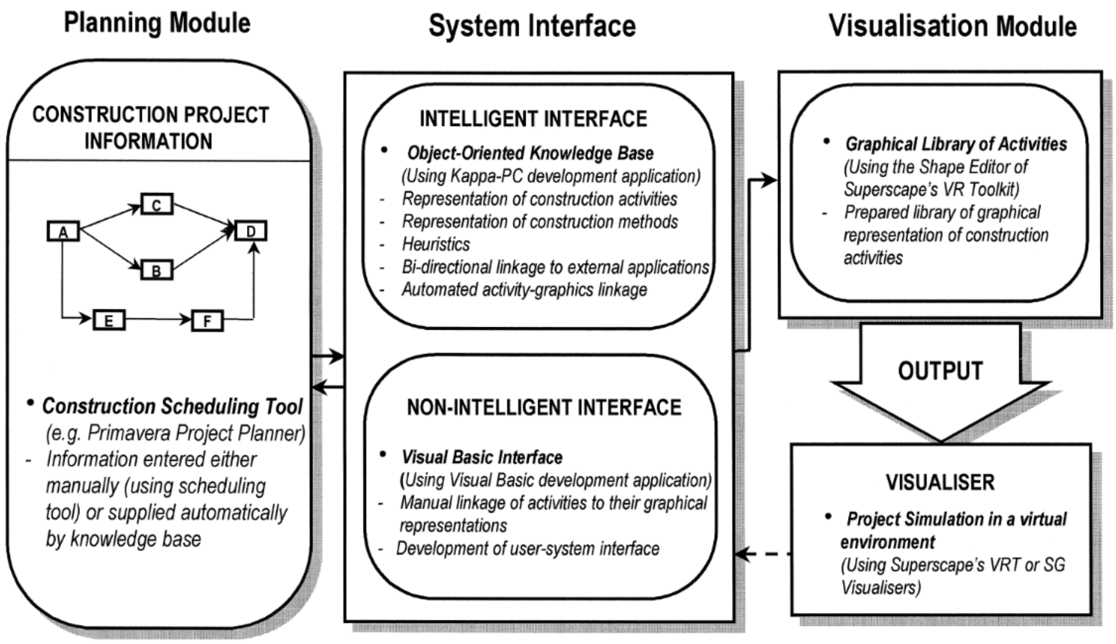
The author used Superscape's Shape Editor Software to create a graphical library for the site elements such as foundations, columns, beams, slabs, as well as auxiliary activities such as scaffolding, gantries, heavy plants and concrete formworks, etc. Moreover, the site photos were used for mapping each element with its representation in the created library to represent the as-built status for construction. The mapped as-built items enabled automatic interface linkage with the as-planned schedule, which accordingly allowed for displaying the progress status as a dynamic 3D view of the site using VR to check the progress status at any given date.

3.3.1 System architecture

The system architecture was phased as planning module, system interface and visualisation module described as follows:

A. **Planning module**: the main goal for this phase was developing the as-planned schedule. Traditionally, this tended to be achieved by manual inputting *construction project information* into Primavera planning software to develop the base line program to form the basis for comparing the construction performance. *Construction project information* is essentially construction activities and required resources (i.e. workforce, machines, equipment, etc.).
   However, and for the purpose of automation, the proposed system employed the *"planning knowledge base-software"* to automatically input the construction project information. Consequently, the data fed into the system was not the same as the company's rate of productivity, it was however the international rates of productivity uploaded from the planning knowledge software.
B. **System interface:** the key objective of this phase is to build a graphical library of all site elements and then map it with site photos to enable an interface linkage with the scheduled activities in the planning module. It is reported that, the system was flexible to accept manual and automatic mapping process.
   I. Automatic processing is achieved by utilising an object-oriented knowledge base, such as the Kappa-PC development application. This application enables an automatic interlink of all activities into the created library to visualise the progress of the construction activities.
   II. The manual processing achieved by utilising visual basic development software required manual linkage of the activities to their graphical representations.
C. **Visualisation Module**: this phase involved visual checking of the as-planned or the actual progress status for the construction site in a 3D visualisation mode using the VR technology.

The architecture of the system is illustrated in Figure 3.2 as follows:



Source: Retik and Shapira (1999), reused with permission from Arkady Retik

Figure 3.2: Proposed system components and operation.

The proposed system enabled the display of the progress update graphically at any selected date using different colours which assisted the site staff to recognise the status of construction progress (as-built) and its deviation from the as-planned program of works.

3.3.2 Benefits of the developed system

The key benefits of the system enabled a 3D graphical visualisation for the as-built progress status for further comparison against the as-planned schedule. Additionally, the system used different colours for easy recognition of the achieved progress.

3.3.3 Limitations of the system

A. The system relied heavily on manual inputs in its first two phases, which required continuous manual feeding for each activity/sub-activity and linking it manually with its required resources.

B. In fact, the library that was created was the hub of the system, and the main assumption for the reliability of the system was creating a comprehensive library that included details of all of the construction elements. However, developing a library for a construction site requires tens of thousands of clear site photos (Smola and Vishwanathan, 2008), which was not reported in the published research. Moreover, the library should encompass every element in the project, and any missed elements inevitably results in wrong outcomes and accordingly, misleading the decision makers risking unsound decisions.

C. Additionally, using a generalised system for the construction industry was challenged mainly because the library varies from one project to another based on the types of activities.

D. Fundamentally, the creation of the library required determining all of the site elements to be represented as objects. Therefore, after building the library adding any additional object was a laborious task that required additional time.

E. The research did not mention how the occlusions of auxiliary structures and machines were managed.

G. Photos collected from the site were the main pillars of the constituent inputs for the system. Accordingly, the accuracy and correctness of the system is linked with the captured photos. However, there are several attributes which can affect the accuracy of the captured photos, such as the camera type, the cameras' Field Of View (FOV), the cleanness of the photo and its resolutions, the professionalism of the photographer, etc.

H. The system was subjective, as it relied heavily on human intervention which made it prone to errors and time consuming. Consequently, the system was not fully automated.

The realised limitations for the above-mentioned system motivated researchers to propose different technologies. Abeid *et al.,* (2003) have proposed a system PHOTONET II, a software platform aimed at minimising the disputes amongst project parties, which interconnects the recoded film clips with construction schedule and progress information. This system enabled the project stakeholders to playback and visualise the recorded progress and construction actions in few minutes instead of tens of recorded hours. Abeid et al., (2003) further research has utilised the ***time-lapse technique***.

3.4 Time-lapse technique

3.4.1 Historical glimpse of time-lapse technique

Time-lapse is not a new technique and backdates to 1960 when Fondhal (1960) proposed using the time-lapse technique for the first time to analyse construction operations. Later, in 1970s at the University of Michigan, Professor Robert B. Harris presented to students of the civil engineering construction module, the 3-month construction for a pedestrian bridge, in 15 minutes using the time-lapse technique (Everett *et al.,* 1998). The literature revealed that Paulson's endeavours in 1978, was the first attempt that sought to automate data collection from construction sites by using time-lapse. In 1989 the University of Michigan awarded a contract for earthmoving and the time-lapse technique was developed further and used to resolve many disputes amongst the project stakeholders.

The client estimated the quantity of the earthwork as 765 m^3 whilst the contractor claimed it was 2,290 m^3. accordingly. Both client and contractor reviewed the time-lapse records to settle the dispute, revealing the contractor's claimed volume was overstated whilst the client's calculation was understated. With the aid of the time-lapse technique both parties amicably settled the arisen dispute without having to enter into any formal dispute resolution approaches (Everett *et al.,* 1998). Subsequently, many researchers used the time-lapse technique to automate monitoring and controlling construction activates (Everett *et al.,* 1998; Kannan, 1999; Abeid and Arditi, 2002; Abeid and Arditi, 2003; Abeid *et al.,* 2003).

3.4.2 Definition of time-lapse technique

The time-lapse technique is defined as *"a motion picture made so that when projected, a slow action appears to be speeded up"* (Webster's New Dictionary, 1990).

The literature study revealed that the most prominent time-lapse research with regards to the construction industry belongs to Abeid *et al.,* (2003), as detailed in the next section.

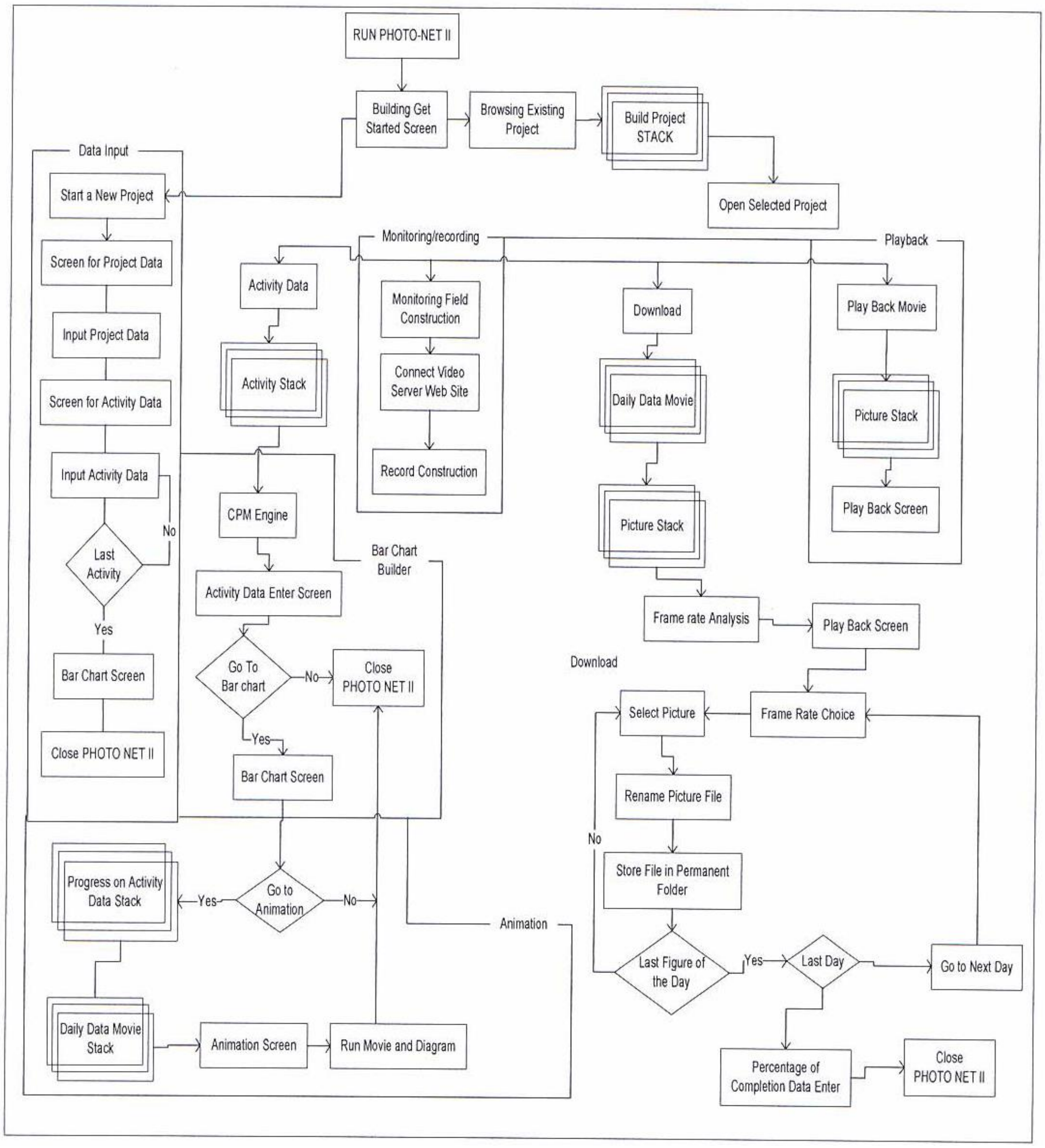
3.5 Research title: PHOTO-NET II: a computer-based monitoring system applied to project management

In his research Abeid *et al.,* (2003) developed the PHOTO-NET II system which sought to monitor the progress in construction sites by integrating time-lapse digital movies for the site activities with the Critical Path Method (CPM). The system was developed to accept the digital photo stills captured from four cameras and storing them chronologically to be further saved in a website database that contained the construction schedule. The main premise of the system was to enable playing back the recorded tens of hours of the construction activities in few minutes using the time-lapse technique. Additionally, PHOTONET-II enabled the main contractor and the client to monitor remotely the progress of the construction site from the office in a real time live stream.

The system recognised and stored photos captured on high frame rates for the construction site activities. These captured photos were displayed in sequence to create a film for the site in a high frame rate using the time-lapse technique to reduce the display duration. The developed system gave users the chance to select from different frame rates for display. The selection was based on what specifics the users wanted to review. For example, if there was an accident, accordingly, the selected option would be slow rate with clear details, and hence, 15 frames per second (fps) is considered the best option. However, if the task was just monitoring the overall site with no specific requirement for detail the 30 fps would be a good option.

3.5.1 System architecture

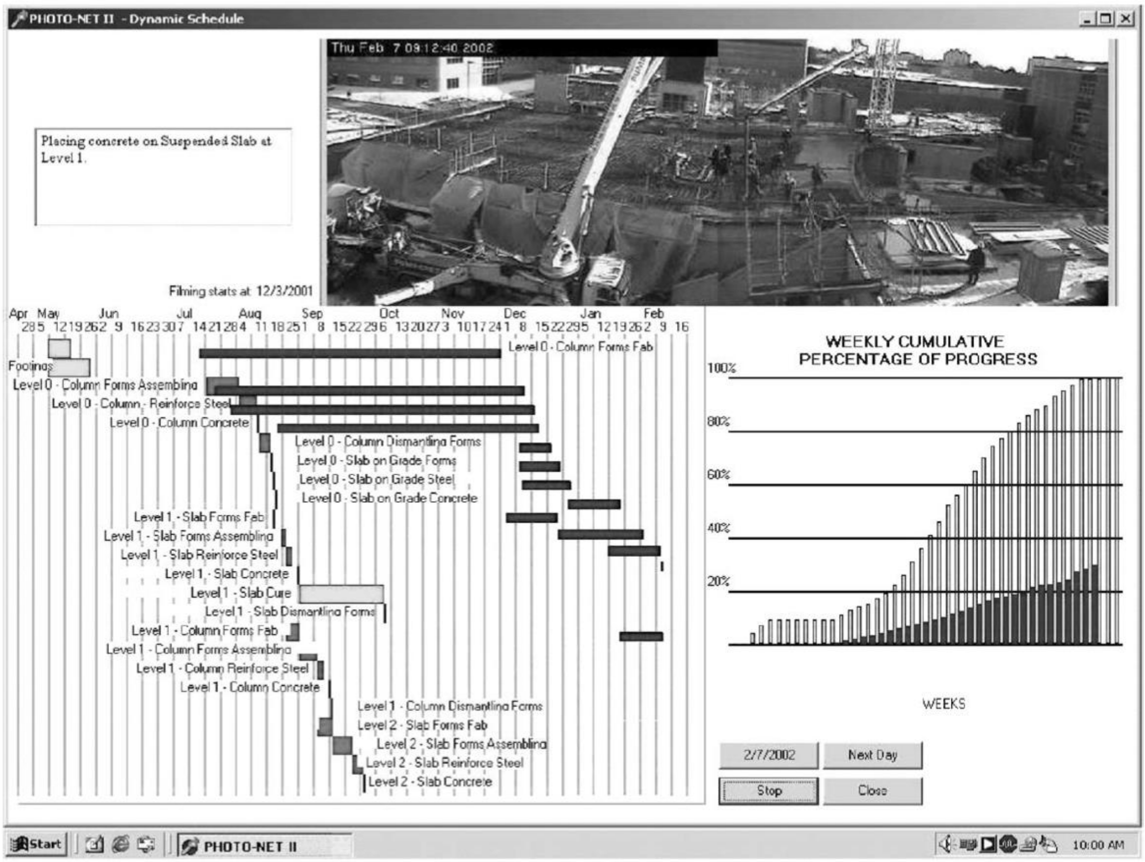
PHOTONET-II system is a software platform developed by using the Delphi programming language. The system uses four programmed analog Pan, Tilt and Zoom (PTZ) surveillance cameras fixed on site to capture photos in stable rate (fps). Cameras were installed in selected positions in the construction site to enable the capture of key activities. These cameras were connected through coaxial cables to a video server. The video server is a device capable of receiving and storing analog photos at a rate up to 30 fps and could be installed at any location where it could be connected to a broadband Internet connection. Moreover, an essential standard unit required to run the system was a microcomputer with an Ethernet card and a hard disk of at least 20-Gb capacity. This computer could be placed anywhere provided that an Internet broadband connection was available. To enable recognition of the progress status, preparation of the as-planned construction schedule was a prerequisite, to compare it against the data collected from the site which represented the as-built. Figure 3. 3 demonstrates the workflow of the system.



Source: Abeid et al., (2003, pp. 612), reused with permission from Elsevier

Figure 3. 3: General flow chart for PHOTONET II system

The workflow of the system starts by arranging the stored photos chronically for further processing in order to enable play-back time-lapse video for visual checking of site activities. Moreover, the system displayed two different bar charts, the first was bar chart which displayed the as-planned versus the as-built, and the second was the accumulative as-planned progress versus the as-built progress in percentage, Figure 3.4 shows a screen shot of the system. The system also enabled play-back of a video with the time-lapse technique for the records of each camera separately as shown on the top view of Figure 3.4.



Source: Abeid et al., (2003, pp. 606), used with permission from Elsevier

Figure 3.4: Screen shot for PHOTO-NET II

3.5.2 Benefits of the system

Due to Photo NET-II, the number of site visits were remarkably reduced as the site could be monitored remotely. The system assisted the contractor to realise his actual rate of productivity, which could be used for bidding on new projects. Moreover, equipment, delivery of materials, and staff performance were visually monitored from the videos of time-lapse for the recorded images.

Ultimately, the system assisted in settling some disputes pertaining to the interim monthly payments based on the acquired data that was accepted by the client as well as the main contractor. The impact of adverse weather was investigated easily for verification of the contractor’s entitlement for time compensation, and accordingly, the system contributed to reducing formal claims and disputes between parties.

The system was tested in a real case study, which was successfully used to monitor the construction of a six-storey educational building located on the University of Waterloo campus; the construction started in July 2001 and completed in December 2002.

3.5.3 Limitations of the system

Photo-net-II system uses only four cameras which were not enough to cover all construction activities in detail, mainly because the camera's FOV was usually limited to a certain length, measured from the camera's sensor to the target object. Consequently, several activities were not captured, as they were outside the camera's FOV, and thus the updates could mislead the decision-makers and result in unsound decisions.

Moreover, the published research did not address how the system dealt with site occlusions. Occlusion is defined as any blockage of the camera vision by a physical object (Chi *et al*., 2016). Occlusion can be classified into two main categories based on the source; static occlusion which is the result of a static object (such as scaffolding, steel rebar, timber, etc.), and dynamic occlusion which is a result of movable objects (such as labourers, machines, etc.). Indeed, it is extremely difficult to obtain a clear image without occlusions. On a construction site, occlusions are inevitable (Ibrahim *et al.,* 2009; Dimitrov and Golparvar-Fard, 2014).

Also, cameras were exposed to continuous disturbance for video recording due to repetitive damages to the power cables that connect the cameras to the field computer. It is practically impossible to protect the power cables from damages in a dynamic construction site that is full of different types of equipment, light and heavy machines such as crawlers.

On the other hand, the continuously recorded videos for the construction site required huge hardware storage especially, at the tenure of the case study. The system overcame this challenge by compressing the files to reduce the file size by 80% using JPEG format. However, the compression process adversely compromised the quality of the photos.

As highlighted by the authors, manual intervention was fundamental for operating the system. Although, the system run the comparison between the as-built and the as-planned for construction activities as shown in Figure 3.4, the system lacked the ability to show the progress for each activity in percentage terms. Accordingly, the delayed activities are not recognised, and manual investigation is required to realise the delayed activity. Practically, to establish the percentage and status for each activity, the project manager will need to run the time-lapse video and watch closely all construction activities to find out what activities that did not start or did not evolve according to the as-planned schedule.

On the other hand, the system was designed for only one user and does not allow multiple users to access the system. Accordingly, PHOTO-NET II required a dedicated administrator to operate the system and copy the recorded videos to the office computer, compress the files and then share the outputs with the project manager and project stakeholders.

Consequently, the accuracy of this system was challenged by the requisite manual intervention and subjectivity which brought about errors, in addition to the required and prolonged processing time. Consequently, PHOTO-NET II is considered inaccurate, prone to errors and subjectivity, unreliable and time consuming.

Clearly, the proposed systems are challenged by the necessary human interventions that leads to subjectivity, errors, inaccuracy and time consuming.

To overcome the abovementioned limitations, researchers such as Chau *et al*., (2004) adopted different technologies. Their system allowed automated visual assessment of progress in construction projects and utilised ***CV*** technology.

3.6 Computer Vision (CV) technology

3.6.1 Historical glimpse of CV

In 1960 in his PhD thesis Larry Roberts from the Massachusetts Institute of Technology (MIT) discussed the possibility of extracting 3D geometric information from 2D views. This proposal received a great deal of interest from researchers both at MIT and in many other parts of the world, particularly those with a particular interest in Artificial Intelligence (AI). Sun *et al.,* (2010) cited that, computer vision and Machine Vision are used synonymously and are a subset of AI.

David Marr (1978) at the MIT research centre made a remarkable paradigm shift for CV technology when he succeeded to build the first 3D module from 2D images. Marr proposed a binocular stereo algorithm wherein images were collected from different predefined views to identify the corresponding points within these images. Marr's 3D module was incomplete due to low capability of technology at that time. Later, Yiannis Aloimonos (1993) from the University of Maryland took the CV technology to another dimension by exploiting the revolution in computer science by developing algorithms that were able to automate the recognition of multiple 2D images to generate a complete 3D module rich with real information. CV is now employed in all parts of life such as construction, medicine, agriculture, sports, criminology, etc.

3.6.2 Definition of CV

Computer Vision or machine vision is a subset technology for AI that enables the computer to interact like human vision to gain a high-level understanding of the captured digital images or videos. Computer Vision utilises algorithms to automate the analysis and recognition tasks to derive the details of the 3D objects from 2D photo stills (Huang, 1996; Zhang *et al*., 2009; Hartley and Zisserman, 2003).

The following research is a successful example of the utilisation of CV within the construction industry as a standalone technology sought to automate the assessment of construction progress.

3.6.3 Research Title: Towards Automated Visual Assessment of Progress in Construction Projects

3.6.3.1 System architecture

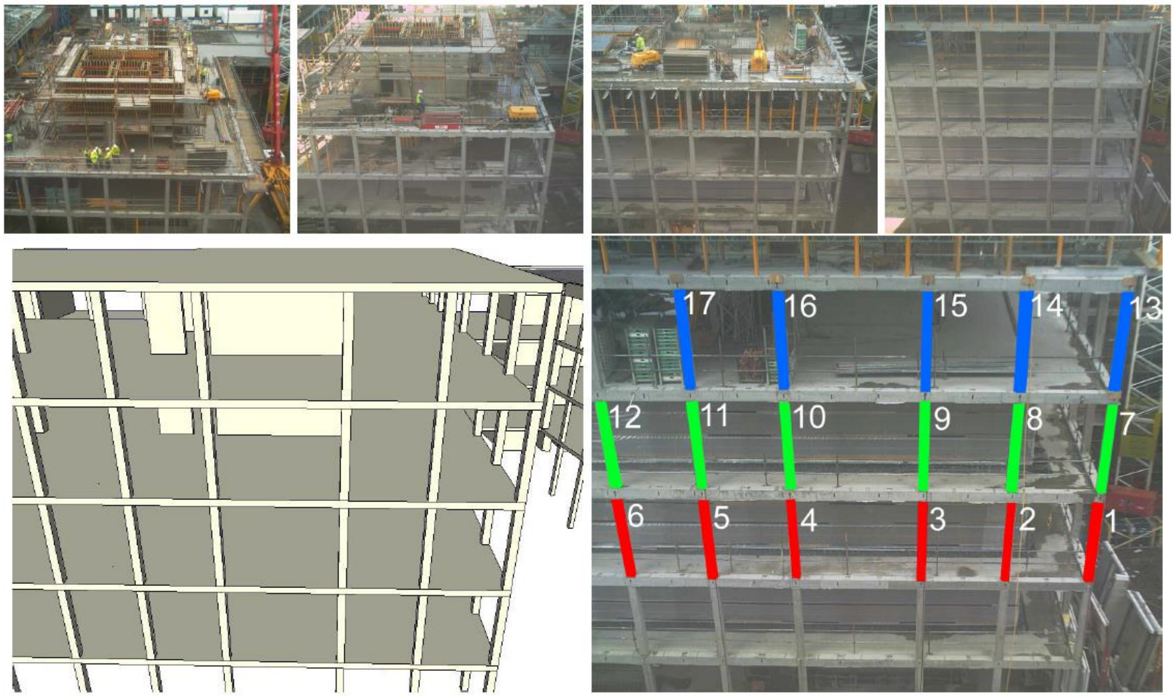
In order to assess the construction progress, Lukins and Trucco (2007) used only one camera to develop a visualisation system. The system's premise was built on detecting changes in the captured photos for one element only (concrete columns). For that end, the camera was fixed in a location that enabled capturing numerous photos for the same element at different times. The system was tested in a live case study at the School of Informatics building at the University of Edinburgh.

Images were captured from the fixed camera every 20 minutes from 9:00 to 15:40 for a duration of four months. The camera location was primarily positioned in respect to the building to enable capturing images of the concrete column throughout its various construction progression stages. Subsequently, the captured photos were aligned with the building model using Particle Swarm Optimisation (PSO) algorithm. The aligned images in the sequence were normalised photometrically to assuage the effects of changing lighting conditions.

The system needed human intervention for the visual comparison of the captured photos to distinguish the progress for the concrete column. For example, photos that were captured on 1st March should be compared with photos captured on 7th March to identify the changes have taken place within this duration to assess the progress status.

As shown in Figure 3.5 the system was built on the following three stages:

A. **Localisation**: this stage involved aligning the components of the building model (i.e. the concrete column) with a sequence of photos.
B. **Detection**: in this stage, the changes that occurred to the building components were spotted over a certain span of time.
C. **Verification:** in this stage, changes are verified to confirm whether the detected changes for the construction element were accurate or the system detected a false element such as a temporary structure (i.e. scaffolding, shuttering or the alike).



Source: Lukins and Trucco (2007), reused with permission from Emanuele Trucco

Figure 3.5: Input data sequence showing typical frames by month (top), with aligned 3D model and resulting template masks for individual columns (bottom)

3.6.3.2 Benefits of the developed system

This system assisted the site manager to recognise visually the progress status of the changes occurred over a time span for concrete columns.

3.6.3.3 Limitations of the system

The system relied heavily on human intervention for manual calculations and visual judgements of the progress status. Consequently, the results were subjective, prone to errors, inaccurate and time consuming.

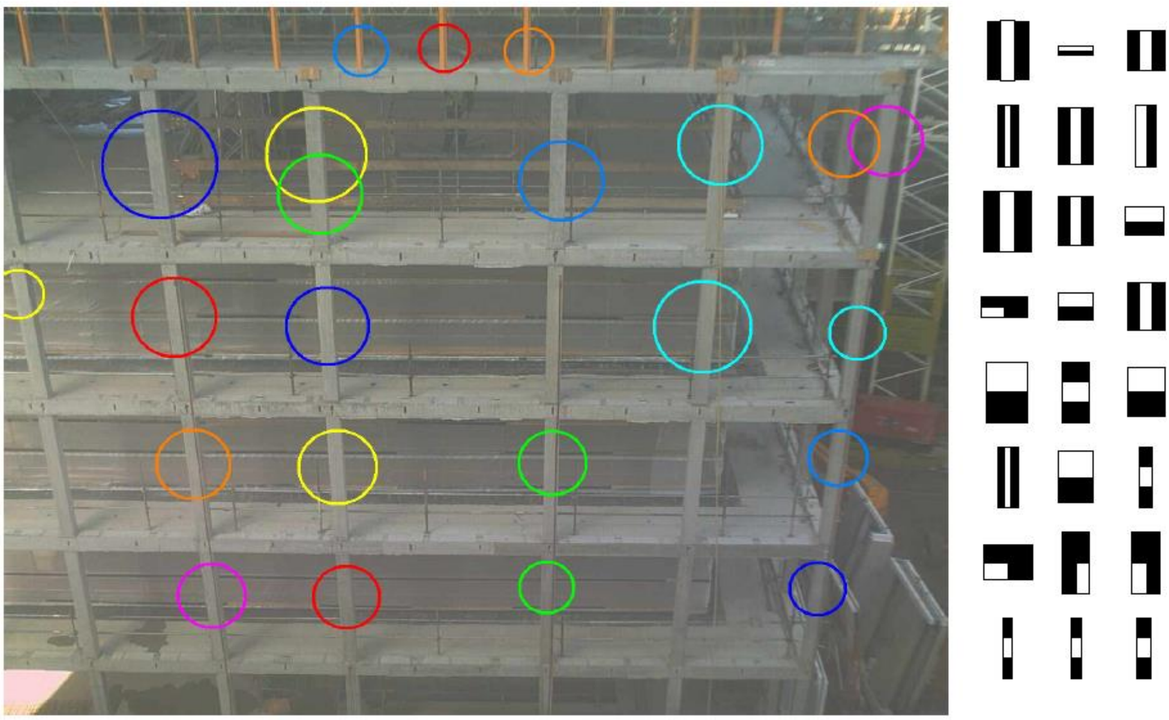
Moreover, the authors failed to program the camera so that it did not capture unnecessary period of inactivity, for example, weekends and as such over four months authors had to manually delete 1,806 needlessly captured photos.

Although, the system was designed for only one construction element i.e. reinforced concrete columns, that camera failed to include all the columns of the building, as the maximum range for capturing photos was up to 100m only for the camera used. Consequently, any column beyond this distance or outside the FOV was not detected. Likewise, most of the details are missed fom the target columns, mainly due to one camera being able to capture the face of the column with the other faces outside of the cameras' reach.

It is worth mentioning that, authors themselves have considered that using one camera as the main limitation for their developed system. As part of the site was captured from only one angle some construction elements were neither tested nor captured in the photos.

To spot changes in the captured images, the system required an algorithm training classifier based on Adaboost algorithm. To ensure accuracy of results, the classifier will have undertaken a long period of training, initially on 100 images, then 1000 images and finally 2000 images. However, the classifier still failed to differentiate between the column (construction element) and the scaffolding (temporary structure).

The following, Figure 3.6, illustrates the limitations of the classifier, whereby, the coloured circles indicate the detected element. It is clear, that the classifier failed to differentiate between the scaffolding and concrete columns; because on the top level of the below figure there are three temporary scaffolding poles that have been perceived as concrete columns. Conversely, the classifier failed to detect and mark 12 out of 36 columns.



Source: Lukins and Trucco (2007), reused with permission from Emanuele Trucco

Figure 3.6: Example output for column detection (left), with Haar features used (right)

Finally, the research did not address how the occlusions of the temporary structures, machines and labours were managed.

3.7 Integrated technology

It is clear that, standalone systems which use single technology have several limitations. Consequently, there has been a quest to integrate two or more technologies to combine their benefits, and to reduce the adverse effects of standalone technology (Ibrahim *et al.*, 2009; Golparvar-Fard *et al.,* 2009; El-Omari and Moselhi, 2011; Roh *et al.,* 2011; Dimitrov and Golparvar-Fard, 2014; Behnam *et al.,* 2016; Braun and Borrmann, 2019).

Recognising the weaknesses, strengths and limitations of previous attempts have enriched the knowledge to exploit these strengths and avoid the limitations. For example, the literature offered rigorous evidence that the accuracy of LS technology outperformed the photogrammetry technique. However, LS is extremely expensive compared with photogrammetry, thus its cost is cost-prohibitive for many construction projects, specifically small and medium size projects. In addition, LS requires a technician to operate this technology, defining the required settings and calculating how many moves are needed to generate acceptable 3D results which makes this technology time consuming.

Indeed, these limitations can be alleviated by integrating LS and photogrammetry, whereas photogrammetry reduces the number of scans required and therefore cost and the reduction in human intervention required for LS operations. Additionally, using the LS enhances the detail of the captured reality. Thus, integrating these two technologies lessens the limitations associated with each one individually (El-Omari and Moselhi, 2011).

Consequently, the push in recent efforts shifted from the limitations of stand-alone technology to mixed technologies, which addressed the limitations of stand-alone technology and exploited the strengths of these technologies (Omar *et al.,* 2018).

Several researchers have realised the essence of integrating two or more technologies to improve the results of monitoring construction progress. Some of the earliest research on the integration of two technologies was documented by Samir El-Omari and Osama Moselhi who started their research in 2005 with continuous research efforts until 2011.

Table 3.1 shows their endeavours over this time period. It involved research studies that used real case studies for integrating LS and photogrammetry; specifally two of the research projects conducted in 2008 and 2011.

Table 3.1: El-Omari and Moselhi's publications pertaining to integrating LS and photogrammetry technologies

Serial	Research title	Publication year	Journal/Conference
1	The use of 3D scanners for automated progress reporting on construction activities	2005	AACE 49th International Annual Meeting, New Orleans, Louisiana.
2	Integrating bar coding and RFID to automate data collection from construction sites	2006	Joint International Conference on Computing and Decision Making in Civil and Building Engineering ASCE, June 14-16, 2006, Montreal, Canada.
3	Hybrid methodology for automated collection of data from construction sites	2007	International Symposium on Automation & Robotics in Construction ISARC, Kochi, Kerala, India.
4	Integrating 3D laser scanning and photogrammetry for progress measurement of construction work	2008	Automation in Construction
5	Data acquisition from construction sites for tracking purposes	2009	Engineering, Construction and Architectural Management
6	Database driven application for automated tracking and control of construction projects	2010	CSCE Conference, 2010, Winnipeg, Manitoba, Canada
7	Integrating automated data acquisition technologies for progress reporting of construction projects	2011	Automation in construction

El-Omari and Moselhi (2008) proposed an integrated system which circumvented the limitations associated with the separate use of a technology, for measuring the progress of construction work, and to that end they integrated *LS* and *photogrammetry*.

3.7.1 Historical glimpse of Photogrammetry

The word "*photogrammetry*" comes from three Greek words: "***Photo"*** which means ***light***, "***Gramma"*** means ***drawn*** and "***Metrein"*** means ***to measure***.

The literature review reveals that, the concept of photogrammetry was firstly proposed by Leonardo Da Vinci in 1480 when he put forward perspective and projective geometry for analysing and measuring the contents of the artistic paints (Ghosh, 1981). In 1625, the French mathematician Desargues proposed the 'vanishing point' technique to define the projective geometry (Doyle, 1963). And more than two centuries later, in 1849 the Frenchman Laussedat who is known as "*the father of photogrammetry"* used terrestrial images for the first time for topographic map analysis and compilation (Gruyter, 2007). A few years later, in 1858 Nadar used a balloon and camera for capturing images and for the first time, aerial photography was captured. The term photogrammetry was proposed and used for the first time in 1893 by Meydenbauer (Gruyter, 2007).

Photogrammetry started with conventional photography and the further development of photogrammetry was undertaken in three phases according to the advancement of utilised technology. The first development was *"analogue photogrammetry"* wherein processing was by means of optical-mechanical instruments such as *"old model cameras"*. The advent and involvement of the computer, pushed the boundaries of the photogrammetry to the next advancement level for processing and analysis which is so called *"analytical photogrammetry"*. However, scripting photogrammetry its real history started in 1950 in line with the introduction of the computer, significant advancements to photogrammetry were made after that date resulting in the second key development. Consequently, the third phase called *"digital photogrammetry,"* saw great progression and changed the concept of recording the reflected light instead of sensitive emulsion to be recorded by electronic detectors, which facilitated and eased image analysis and reconstruction.

Types of photogrammetry:

The literature study shows that, there are two main types of photogrammetry: the first is "***close-range photogrammetry"*** wherein the distance between the camera/LS and the object is not more than 100m (Ibrahim *et al.,* 2009). However, the second type is "***long-range photogrammetry***" or commonly known as photogrammetry, where the object distance could be more 100 m depending on the features and ability of the camera or the laser scanning machine to accurately capture the details of the object.

Capturing the data can be from aerial photography using UAV equipped with camera/LS or stationary cameras (Kelly *et al.,* 2006; Larsen *et al.,* 2017). Technically, the modern digital camera is a composite of sensitive sensors which can be programmed and wirelessly connected to the internet to transmit the captured images directly to the data silo (Hikvision, 2019).

3.7.2 Definition of photogrammetry

Photogrammetry is defined as the science of obtaining reliable information about the properties of surfaces and objects without physical contact with the object. It is also known as the science of reconstructing positions, shapes and sizes of objects from images, which can be done by either using cameras (Doyle, 1963; Ghosh, 1981) or LS machines or both (Gruyter, 2007; Bosché, 2010).

3.7.3 Laser scanning (LS)

Although LS is a new technology that appeared for the first time in 1990s, the literature study suffers from a scarcity of reliable records about the development history of the LS. This perhaps can be attributed to the fact that, LS is not a one-man invention but rather is a collective collaboration of co-operation. The available literature depicted the timeline of LS as developed by Cyra Technologies in 1994, which was acquired by Leica Geosystems in 2001. However, there is much literature about the advancements of LS technology since 2000s (Ebrahim, 2014).

LS is also known as Light Detection And Ranging (LiDAR) and Terrestrial Laser Scanning (TLS).

Types of Laser Scanning:

There are two main types of laser scanning, determined by the scanning range and the target.

The first technology is Light Detection And Ranging (LiDAR) which allows for rapid, accurate and dense spatial details for morphologically complex areas. LiDAR is essentially ground based which also means it is Terrestrial Laser Scanning, with the ideal distance for this technique being a maximum of 100m measured from LS machine to the target object (Larsen *et al.,* 2017). LiDAR is widely used in several industries and applied to numerous fields such as seismology, construction, archaeology, and street mapping, etc. (Cracknell *et al.,* 2007).

The second type is Laser Distance And Ranging (LADAR) which has the ability to function the same as LiDAR. However, it is principally used for large areas such as earthworks, terrains, topographic mapping, city scanning, military, and forestry. LADAR has the ability to be attached to airborne or UAV devices. Notably, aerial laser scanning term is keyed to LADAR (Kelly *et al*., 2006; Zhou and Devore, 2008).

After a comprehensive study of the literature, it should be mentioned that several researchers have used the three terms LADAR, LiDAR and TLS synonymously.

LS mechanism of action:

Generally, the principle of operation for LS is to send a pulse of laser beam from the LS machine to the object, the laser reflects to the machine's sensor. *Technically, the LS machine is a composite of tens of very sensitive sensors.*

The distance between the object and the machine ($\boldsymbol{R}$) is called the "Range" of the laser beam. This range varies according to the machine's model. The Time ($\boldsymbol{T}$) required to scan an object is expressed in

$$T = \frac{2R}{S} = \frac{2 \times 500}{299792458} = 3 \times 10^{-6}$$

T is the time taken for a laser beam to make a round-flight ($2R$), where (S) is the speed of light.

The time required to scan an object allocated on 500m from the LS machine scanning is 3 microseconds ($3 \times 10^{-6}\ Second$).

Every pulse generates a point in the 3D point cloud, that entails the x, y, z coordinates and colour details (Larsen *et al.,* 2017).

3.7.4 Definition of Laser scanning

According to Ebrahim (2011) Laser scanning is a technique used to collect physical details of real-world (i.e. object or environment) without physical contact with the objects, and the captured data is in a form of ***3D point cloud models***.

3.7.5 3D Point cloud model

The 3D point cloud model tends to be built automatically from data collected by the LS as an output of its operation. However, using the photogrammetry technique entails using software to convert the 2D captured photos into a 3D point cloud model. Thereof, the software defines the minimum number of photos that need to be captured in a predefined technique to cover all the details of the object including overlaps between every two consecutive 2D images (AgiSoft Manual, 2017). To convert these photos to 3D point cloud model and analyse the encapsulated information, there is a wide range of software that is availbale to perform that task such as, AgiSoft PhotoScan Pro from AgiSoft, ContextCapture from Bentley, ReCap Photo from Autodesk, and Pix4 from Pix4 (Ustinov and Bolodurin, 2016; Braun and Borrmann, 2019).

Typically, the point cloud for an object consists of thousands or millions of points, as the image unit is "***pixel***" the unit for 3D point cloud model is "***point***". Each point entails the coordinate X, Y, Z and details of Red, Green, Blue (RGB).

3.7.6 Definition of 3D point cloud model

It is the 3D shape constructed from the captured object in a form of thousands or millions of points generated from LS or processed images of photogrammetry (Klokov and Lempitsky, 2017) refer to Figure 3.7 and Figure 3.8.

The research outlined below, is a successful example of integration of different technologies such as LS, photogrammetry and 3D point cloud in construction projects to automate progress measurement of construction work.

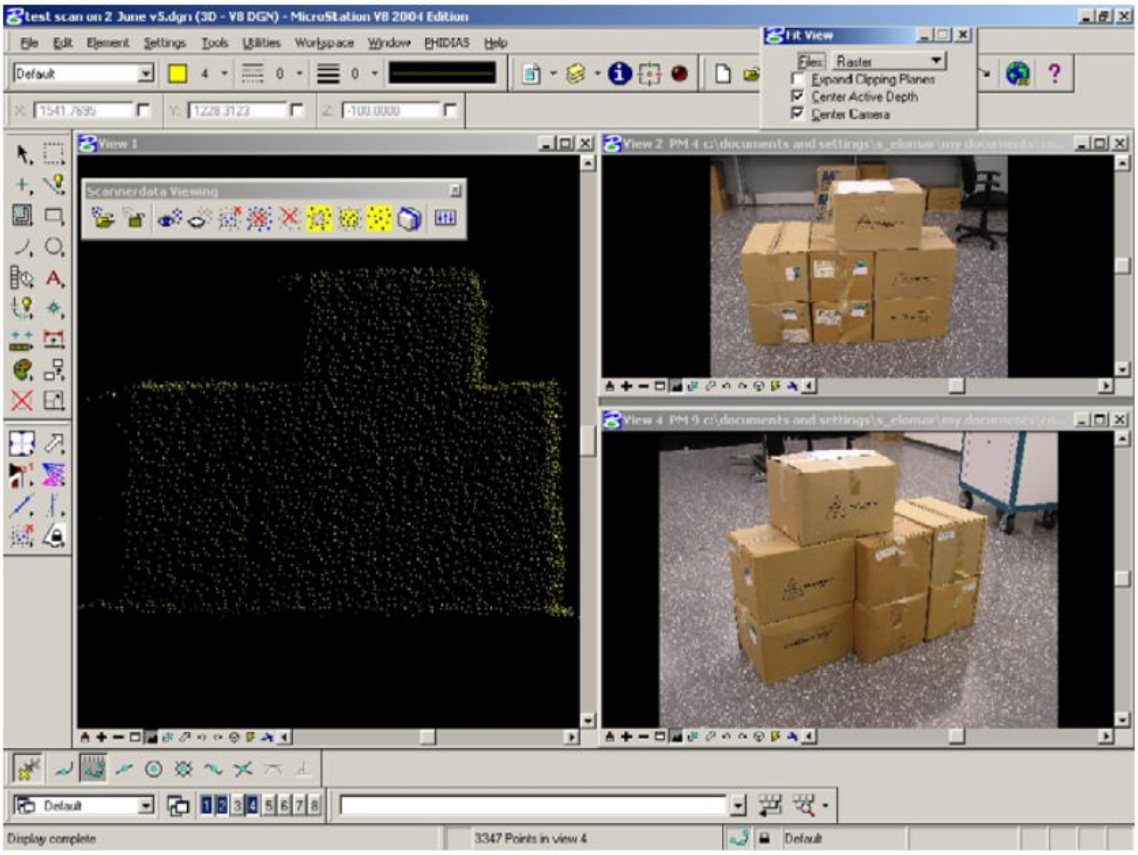
3.8 Research title: integrating 3D laser scanning and photogrammetry for progress measurement of construction work

3.8.1 System architecture

The comprehensive study of literature revealed that, this research is the first endeavour of integrating the LS and photogrammetry technique together. The authors tested the proof of concept in the laboratory as an experiment prior to testing it in a real-life construction project. To that end, they used LPM 100 VHS LADAR of Riegl LS machine and the digital camera was Olympus C750.

They sought to acquire the highest accuracy from their integrated system, for that, they tried 17 different alternatives for capturing the details of the objects using LS and cameras to deduce the most acceptable level of accuracy, for the results. Their prime objective was to reduce the number of LS moves to decrease the cost and complexity of using LS machines, and therefore, they fixed the LS machine in one position to scan one side only for the seven objects shown in Figure 3.7.

However, the other three sides of the same objects were captured using the handheld camera (Olympus C750). The captured details from both technologies were converted into a 3D point cloud model using RiPROFILE software; the two **point-clouds from both** techniques (i.e. LS and photogrammetry) were stored directly in a laptop. Next the two point-clouds were synchronised and integrated into one point-cloud using PHIDIAS software. And to enable the users to extract the details and measurements from the integrated point cloud model, it was imported to the CAD-system MicroStation as depicted in Figure 3.8.



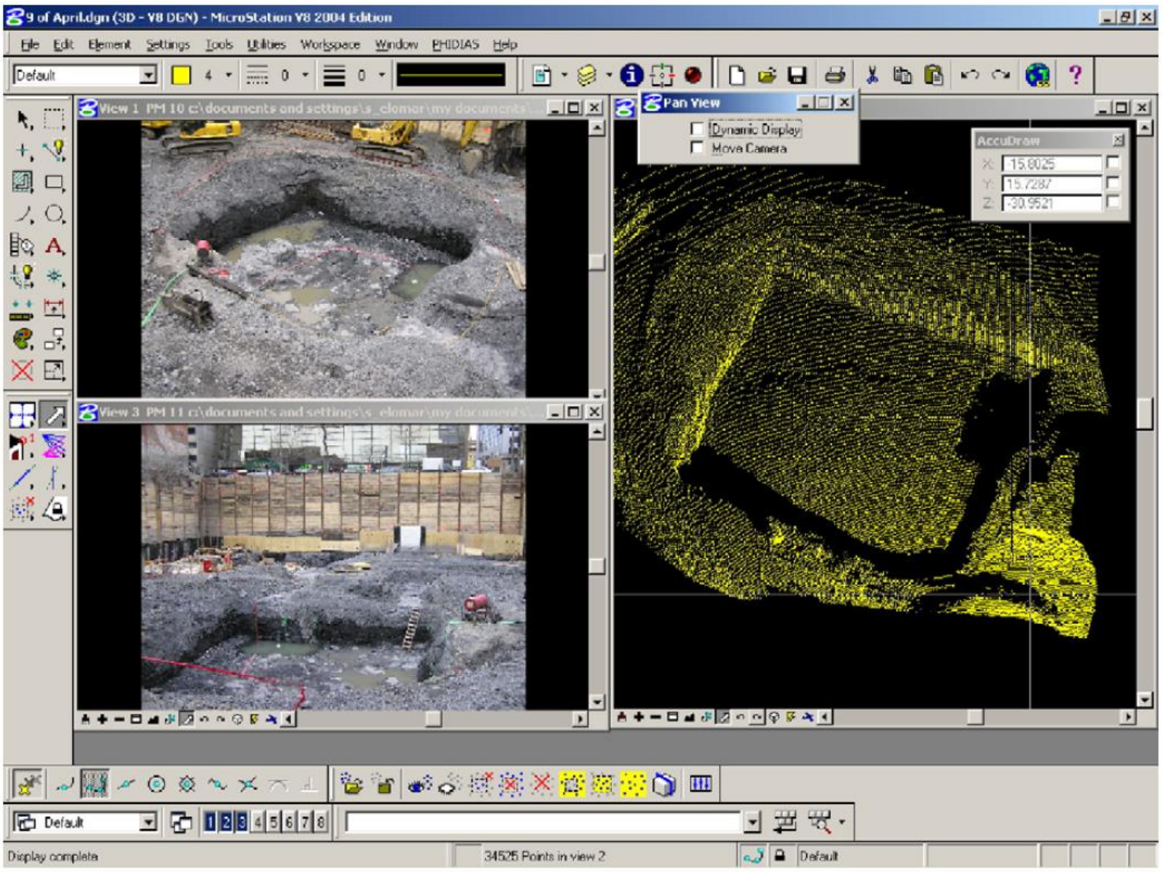
Source: El-Omari and Moslehi (2008, pp.5), reused with permission from Samir El-Omari

Figure 3.7: The constructed 3D point cloud based on the laboratory experiment

After the successful implementation of the lab experiments, authors tested the integrated system in a real case study for a construction site at Concordia University in Montreal. The dimensions of the construction site were 60m×40m, and the same concept used for the laboratoy experiment for data capture/collection was repeated in the case study. The results from the first-time attempt of integration between LS and photogrammetry technologies from the site was relatively satisfactory. Figure 3.8 demonstrates the 3D point cloud that is constructed from the integration of the LS and photogrammetry, which is further used for determining the progress status.

The authors reported that, the accuracy of the integrated 3D point cloud model from both technologies was less than expected, but enough to extract the required measurements and details.

On the other hand, the authors accepted the low accuracy of the integrated point cloud for the ability of integration between the two technologies and saving time and cost of the proposed system.



Source: El-Omari and Moslehi (2008, pp.8), reused with permission from Samir El-Omari

Figure 3.8: 3D model with scanned and digital images

3.8.2 Benefits of the developed system

The proposed system achieved tremendous time savings in the data collection process, whereby, the system completed the data acquisition process for the construction site in 21 minutes, far out perfoming 83 minutes using only the LS technology. This meant the system succeeded in saving approximately 75% of the time required to scan the site.

This integration between the LS and photogrammetry opened the door for developments of further integrations between different technologies.

3.8.3 Limitations of the system

The system relied heavily on the manual interventions at different stages, wherein, selection of the suitable photos with less occlusions and noise and uploading selected photos onto the RiPROFILE software for building the point cloud model were manual processes.

In order to synchronise and integrate the two point-cloud models, that were built using the two technologies, the common points between the two point-clouds were visually recognised using a tool in PHIDIAS software is so called “Special Resection.”

Estimation of the progress status and the corresponding percentage involved manual interventions to measure the dimensions from the imported 3D model into MicroStation. Evidently, the proposed system required human intervention for data inputting, processing, quantifying the progress and finally to compare the as-planned progress against the actual progress. Again, this manual intervention is prone to subjectivity, errors and is time consuming.

On the other hand, the authors fixed additional digital camera on top of the LS machine to facilitate synchronisation process between the point clouds obtained from the LS and that obtained from the main camera.

The published research did not make reference to how construction occlusions were dealt with.

The maximum range of the LS machine that was used was 50m, despite the field test demonstrating that the best results were achieved at a maximum range of 30m. Consequently, the number of points and their resolutions in the built 3D point cloud were poor as reported and shown in Figure 3.7 and Figure 3.8.

Furthermore, the proposed system was able to develop only 227,976 points that formed the 3D point cloud model, whereas, Autodesk (2019) cited that the minimum number of points in a 3D point cloud model should not be less than 500,000 points to ensure an acceptable level of accuracy. The authors stated that to acquire a point cloud model with high accuracy, the site required 42 hours of continuous scanning. As a result, the accuracy was poor, and several activities required manual processing. Moreover, scanned images lacked the detail pertaining to the texture and colours. And hence, the accuracy and reliability of the proposed system were doubtful.

Although the proposed system has reduced the operational cost due to installing the LS machine in only one position. However, the cost of renting or purchasing LS is still unaffordable for a wide range of projects, particularly small and medium sized projects.

In their attempt to overcome the abovementioned limitations, Ibrahim *et al.,* (2009) proposed a system that sought to automate the process of the acquisition of site data to eliminate subjectivity and provide on-demand feedback of the progress status. The proposed system has integrated the CV technique and BIM to develop an automated progress assessment system.

3.9 Research title: Towards automated progress assessment of work package components in construction projects using computer vision

3.9.1 System architecture

The proposed system enabled responsive observation driven feedback for progress monitoring based on detailed Work Breakdown Structure (WBS). To that end, the project schedule was broken down into manageable and measurable work packages.

The proposed system employed CV technology to automate the process of assessing the construction progress incorporating two main steps as follows:

- The first step involved modelling and assigning the construction components to work-packages based on predefined criteria from the WBS. WBS criterion was built on dissecting construction elements to its chunk.
- The second step utilised automated tools to interpret the captured images from the site for assessing the status of completion for WBS components to enable evaluation of the progress for work-packages.

The fundamental premise of the system was dividing the construction site into work packages, for example each floor has a work-package, which contains a set of columns, beams etc. with predefined details.

The system used calibrated cameras with predefined locations(X, Y, Z). The cameras' intrinsic and extrinsic properties were calibrated. Cameras were programmed to capture photos between 9:00 AM to 3:00 PM, one photo every 15 minutes (25 photos per day) with a frame size of 1280×1024 pixels. Cameras were aligned and placed 17m away from the building to capture the maximum details of the construction site. The photos were firstly converted to greyscale and partitioned into 64× 64 blocks; this process sought to remove the shadow and sun lighting effects.

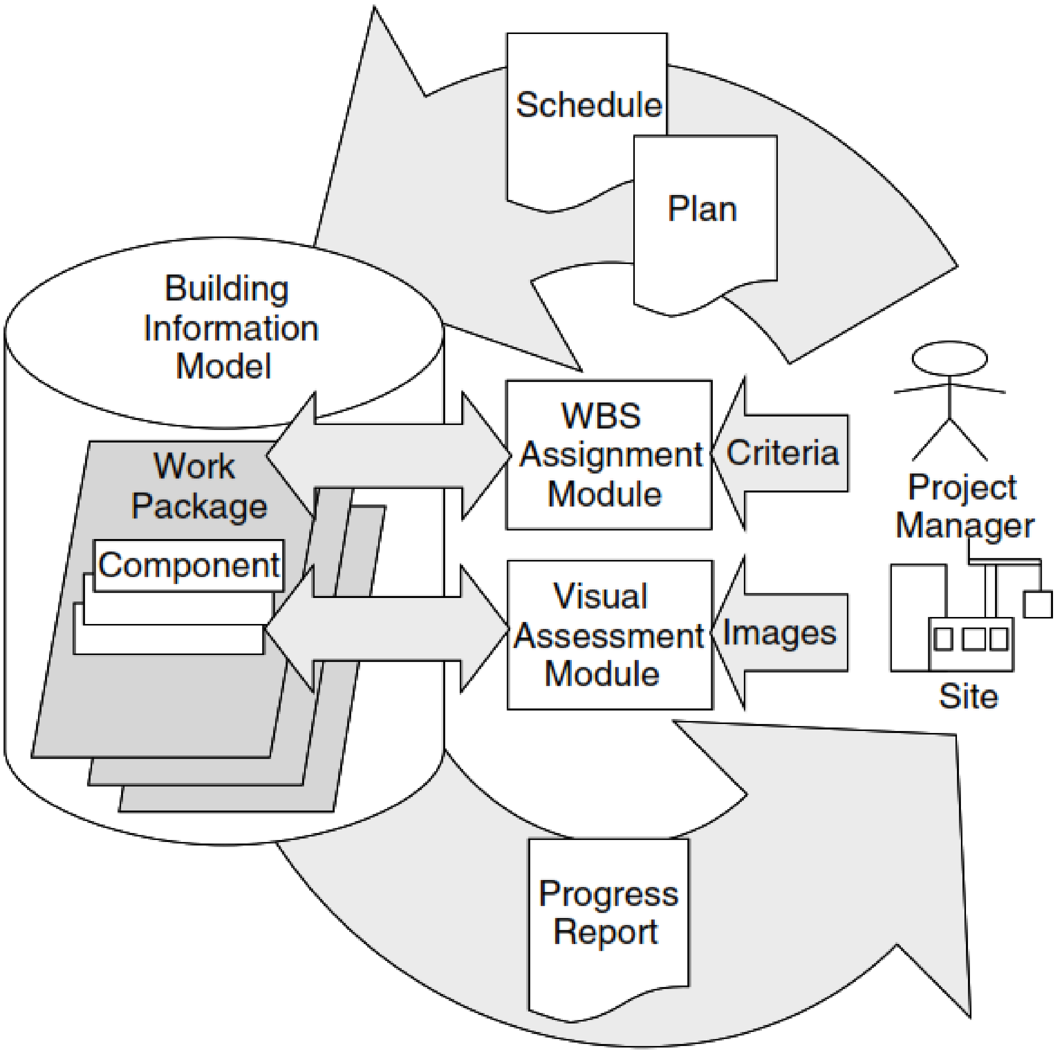
The fixed cameras captured photos to record *change events*. *Change events* relate to changes in the work-packages with the construction progression time which represented the daily progress status. These changes were detected by developing an algorithm that enabled a comparison of the ever-changing array of values, across which were observed changes for each local pixel neighbourhood, for the same element to detect the highest change over that time. The system's framework is depicted in the below Figure 3.9.

The element is considered completed when the predefined rules, developed from algorithms, for a construction element completion logics were accomplished. For example, if the slab for the third floor was completed that implicitly meant columns, beams and slab for the second floor were completed. Accordingly, the system was performing automatic updates for the 3D BIM model to illustrate the progress status at any given time.

The system aligned the captured photos with the work-package as a reference and continued to repeat this action to compare the changes in the photos against the time for each element in the work package to determine when this change occurred. In other words, the system re-projected each individual component onto the aligned building model through the "virtual view" onto the position where it intersects with the image as the criteria for segmenting each individual task as shown in Figure 3.10.

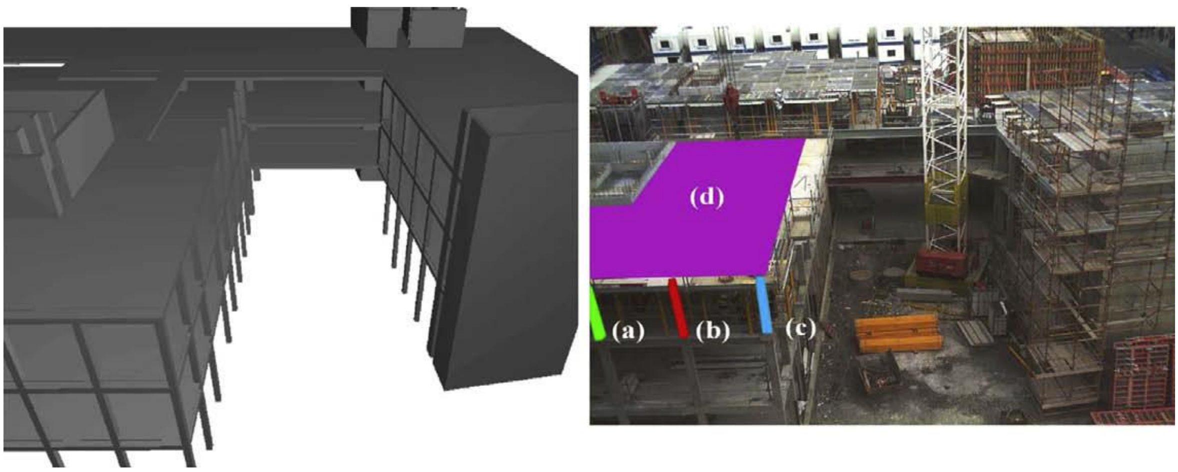
Ultimately based on the analysed information, the construction progress reports status were produced by the system.

The following Figure 3.9 demonstrates the structure of the system.



Source: Ibrahim et al., (2009. pp. 95), reused with permission from Yahaya Ibrahim

Figure 3.9: The automated progress measurement framework



Source: Ibrahim et al., (2009. pp. 100), reused with permission from Yahaya Ibrahim

Figure 3.10: Alignment of camera and resulting masks for four components

3.9.2 Benefits of the system

The system was easy to use and according to the comprehensive literature study, it is the first system that employed BIM to automate progress assessment for construction projects. Moreover, it was cost effective system as it used only one camera.

3.9.3 Limitations of the system

- The system failed to cover the entire construction site for monitoring progress status, as the fixed camera did not capture details of all construction site activities, largely due the camera only being able to capture images within its FOV. Consequently, the progress details for various activities were not included in the system which resulted in partial data acquisition. Accordingly, inaccurate and misleading progress reports were developed.
- Moreover, the research did not mention the methodology used for camera calibration. Furthermore, the system was not designed to accept additional site details or random photos captured from handheld devices such as free cameras or smart phones.
- Despite the additional actions taken to improve the accuracy, the validation of the system revealed that the accuracy achieved for concrete columns increased from 27% to 50%. The authors acknowledged with the weaknesses in their system, wherein the system failed to capture details of construction elements that were out of range from the camera. Consequently, the system failed to produce reliable results due to poor accuracy.
- The system lacked scalability and flexibility, whereas, the threshold-based algorithm that was developed to improve the column accuracy resulted in adverse consequences caused by poor synchronisation of the data. Consequently, the system failed to detect construction elements from the photos and failed to reflect them as their respective elements such as slabs. Indeed, the system succeeded only in the detection of concrete columns, and accordingly, the system was unreliable.
- Moreover, the selected capturing time i.e. 9:00am to 3:00pm resulted in noise in the captured images due to glaring sunlight and shadow effects. These hours also represent the peak working hours for any construction site and therefore when the site tends to be occupied with labour, equipment, and machines which inevitably causes occlusions on the captured images. The authors did not mention how they dealt with occlusions.
- The system required human intervention for auditing the progress status, whereas site staff judgment overrules the system's outputs. Although, the system developed

many algorithms, the final assertion of the system's outputs was not from these developed algorithms, but instead visual verification of the progress status for any construction element was the only confident judgement. Accordingly, the system was not truly automated as human intervention was requisite. Consequently, the system was unreliable, time-consuming, and prone to subjectivity and errors.

In their relentless efforts to develop a system that was ready to use in the construction industry, three years after their work as detailed above, Samir El-Omari and Osama Moselhi included additional features and technologies such as BIM, RFID and barcoding over in an attempt to overcome the limitations encountered in their previous system.

Their following proposed system sought to facilitate automated data acquisition from construction sites, to support efficient time and cost tracking and control of construction projects.

3.10 Research title: Integrating automated data acquisition technologies for progress reporting of construction projects

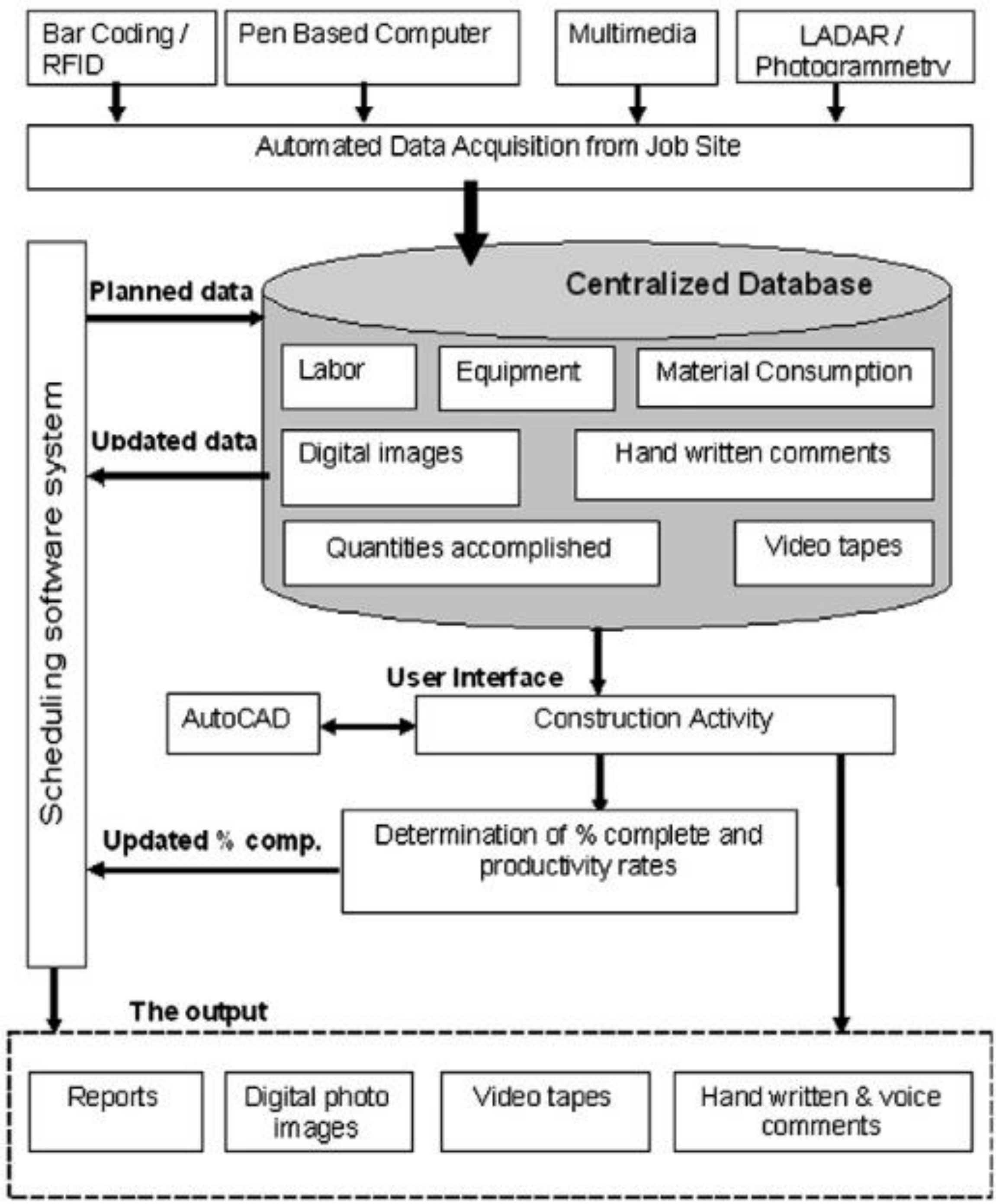
The system designed, from the contractor's perspective facilitated easy recognition of progress updates in a timely manner through the integration of several technologies that enabled automatic data acquisition. LS and photogrammetry were primarily integrated to rapidly track site changes for updating the progress status of the construction site.
Moreover, Radio Frequency Identification (RFID) and barcode technologies were used to collect data for tracking materials and manpower as shown in Figure 3.11; however, these two technologies will not be discussed herein, as they are not relevant to this thesis topic.
The proposed system was tested and validated at John Molson School of Business (JMSB) project, and constructed in Montreal at the Concordia University.

3.10.1 System architecture

To update the construction progress, data was collected from site using LS and photogrammetry technologies. LADAR type (LPM 100 VHS) was fixed in one position, and the handheld digital camera **Olympus C750** used to enhance the site data acquisition by capturing photos of the construction activities. The collected data was stored in a centralised database for further processing to generate the progress report.

An interface software application was developed using Microsoft Access in a pen-based handheld computer (Fujitsu-Stylistic ST4121B) which enabled instantaneous feeding of the data collected from site. The developed interface integrated all the utilised technologies, in addition to management scheduling and drafting software such as BIM, Primavera, Microstation and processing software such as PHIDIAS and RiPROFILE. In other words, the site inspectors captured photos for certain activities and immediately uploaded these photos to their pertinent folders for further processing; this action was repeated for all the acquired data. After storing the acquired data collected by photogrammetry and LS in the centralised database, PHIDIAS software was utilised to integrate the acquired data from LS and photogrammetry, and then RiPROFILE software was further used to convert the integrated data into a 3D point cloud model.

After creating the 3D point cloud model, RiPROFILE software was used to clean and remove erratic points that resulted from construction occlusions before exporting the 3D point cloud model into the quantifying software to determine the progress. Determination of the overall progress status as a percentage entailed assigning weights for each activity. The progress reports were developed according to EVM metrics, and to that end, Microsoft Project software was used to determine the progress status in percentage terms, and quantity. The following Figure 3.11 illustrates the system's architecture:



Source: El-Omari and Moslehi (2011, pp. 703) , reused with permission from Samir El-Omari

Figure 3.11: The architecture of the proposed system

3.10.2 Benefits of the developed system

This integration enabled most of the limitations associated with each technology individually to be overcome, wherein the use of photogrammetry reduced the number of scans and moves required from the LS machine. Moreover, the handheld camera has excluded the limitations caused from inaccessible areas, by circumventing the existing obstacles to capture the target objects. Eventually, the system produced reports in different forms such as quantities and percentages in accordance with EVM metrics.

3.10.3 Limitations of the system

The integration between LS and photogrammetry succeeded in reducing the cost of using only LS, in addition to increasing the accuracy from the sole use of photogrammetry.

However, the direct cost of the LS machine, including the software license and operator's wage, in addition to indirect costs accrued for maintenance remain a major limitation for the adoption of LS technology.

The system relied heavily on the manual intervention for inputting project details and data collected from the daily inspection into the database using the pen-based computer.

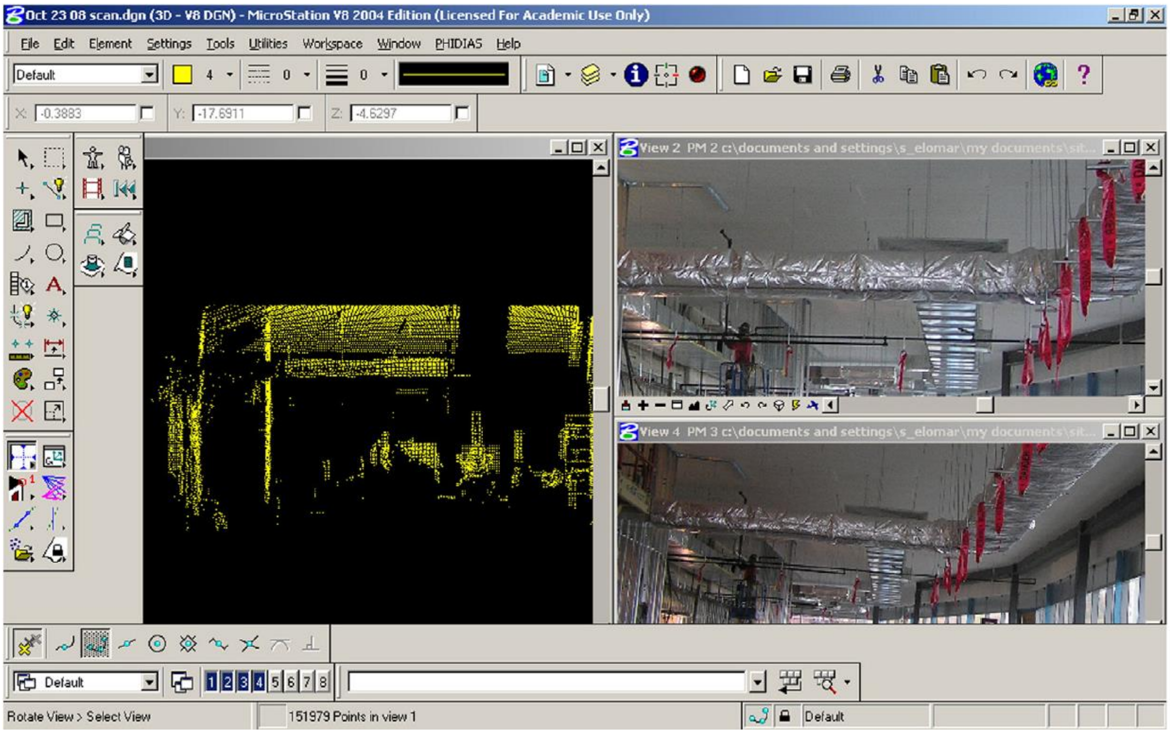
Although, BIM was mentioned in the published research as one of the utilised tools and as an integral part of the proposed system; there is no evidence that the distinctive features and tools of BIM were used for monitoring and updating the progress but only used for material tracking. The proposed system for progress updates relied on 2D drawings at most stages as the comparisons were done between the 2D and 3D CAD drawings developed by MicroStation as shown in the below Figure 3.12.

Moreover, the primary data was collected by the digital handheld camera (Olympus C750) which required a vast number of photos to cover all the details of the construction elements. Thus, the handheld camera with different zooms and focal lens required an extended time for recognition and selection of the images that could be processed. Additionally, the integration process of the images captured by the camera and data acquired by LS was cumbersome, time consuming, and prone to errors, mainly because the selection was done manually based on visual checking.

The system used four different management software programs for data integration and processing; the amount of software used imposed additional costs such as licenses and human resources for training and operations.

Use of the LS machine was usually confronted with limited accessibility in some areas due to ongoing construction site activities or safety issues.

Ultimately, the proposed system failed to improve several limitations from the 2008 proposition, wherein, the 2011 system still suffers from the effects of human intervention such as subjectivity and disposed to errors, and the accuracy and reliability of the system are in doubt.



Source: El-Omari and Moslehi (2011, pp. 702), reused with permission from Samir El-Omari

Figure 3.12: 3D point cloud model from LS and digital images

Roh *et al.,* (2011) attempted to address the previous limitations from their published research. Their research proposed a system that sought to update the project stakeholders for the indoor progress. The system integrated CV technology and BIM as a walk through tool to enable visualisation of the progress to determine the deviations that occurred to the as-planned schedule through a visual comparison between the as-planned and the as-built progress.

3.11 Research Title: An object-based 3D walk-through model for interior construction progress monitoring

3.11.1 System architecture

In order to collect data from the construction site, the system used a handheld camera that captured photo stills for the inside elements. The concept of automatic monitoring of progress status in the interior of the construction can be explained by its three stages (i.e. data collection, data analysis and data integration) outlined below:

- **The first stage** involves data collection of the construction progress (the as-built): In this stage the handheld camera captures photos of the interior construction elements, which entails manual entering, transferring and registering on a 3D model.

Additionally, the contextual data such as time, the name and ID of the element and location (x, y, z) are also manually fed into the system.

The second stage entails data analysis: objects in the 3D BIM model are detected and synchronised to corresponding captured 2D photos.

Moreover, an automatic recognition classifier using CV technology is employed to extract the information and details of the object from the Industry Foundation Classes (IFC). Whereby, the extracted details are transformed to synchronised objects allowing for recognition of the interior construction elements. Afterwards, the coordinates of the as-planned model are aligned with the coordinates of the as-built information. To recognise the progress status for interior construction elements, the model containing the as-built photos is superimposed on the as-planned 3D model.

Accordingly, the progress status can be easily visually recognised through colour coding that represents the progress status for each element. Whereas, 'green' represents ahead of the as-planned schedule, 'red' signifies behind schedule and 'light green' characterises being on track of the schedule as shown in Figure 3.13.

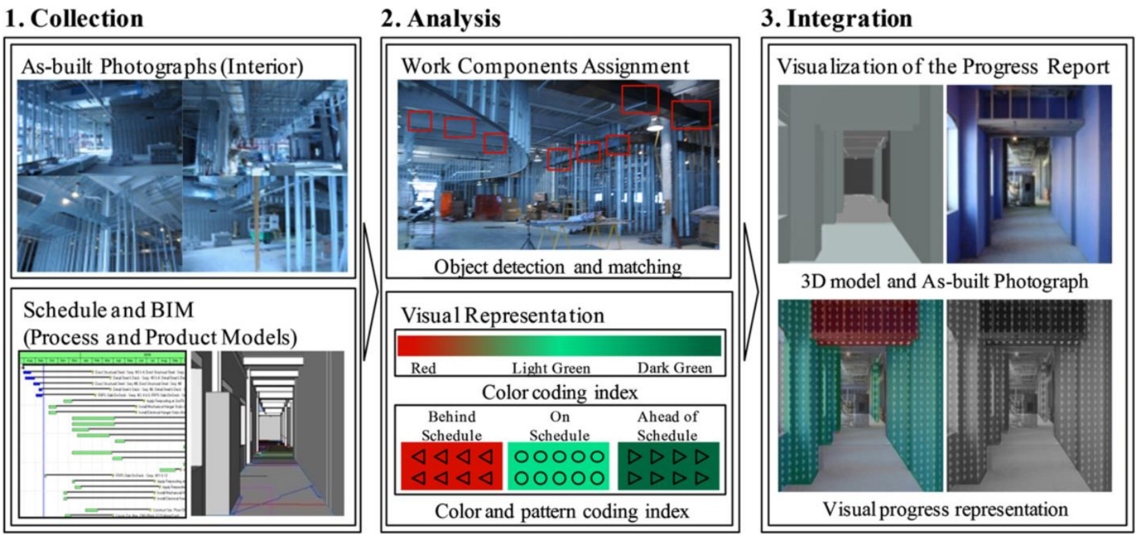
- **The third stage** is visual integration: visualisation of the 3D walk-through model is carried out by utilising Open Graphics Library (OpenGL); Angel (2006) defined OpenGL as a standard specification characterising cross-platform Application Programming Interface (API) for writing applications that produces 3D computer graphics.

  Accordingly, to assist the decision makers to recognise the progress status for each component for the interior construction in a timely manner, a walk-through 3D model was used alongside the 4D model to demonstrate the progress status.

  The authors developed a Ray-casting algorithm based on Open Source Computer Vision (OpenCV) to automatically recognise any deviations between the as-planned and as-built. To train the classifier in deviation detection algorithms, the authors used 661 photos. Ultimately, each interior construction element is automatically highlighted to determine its progress status via the walk-through model.

The system was tested in a construction project at the University of Illinois at Urbana/Champaign of the Student Dining and Residential Hall.

The following Figure 3.13 illustrates the three stages of the system architecture.



Source: Roh et al., (2011, pp. 68), reused with permission from Seungjun Roh

Figure 3.13: Framework of the object-based interior construction progress monitoring system

3.11.2 Benefits of the system

The literature review revealed that, this research is deemed to be amongst the first that proposes a monitoring system of the indoor of a construction project. Indeed, this research solicited other researchers to delve deeper for other methods for monitoring indoor construction works.

The proposed system offers a 3D visualisation environment for monitoring the progress of interior construction elements which were represented in colour codes reflecting the progress status.

3.11.3 Limitations of the system

- Although the proposed system illustrated the progress status for the interior construction elements via a visualisation walk-through model, the authors themselves reported several weaknesses of their system. They stated that "*there are still a number of possible improvements that should be addressed in future research*".
- The proposed system used a hand-held camera to capture random photos for data collection. Accordingly, appropriate registration of the captured photos necessitated capturing various photos of the same element from different positions and levels. Indeed, the system barely succeeded in registering the captured photos, mainly because most of the captured photos lacked the required details for registration and accordingly, the subsequent stages were not proceeded correctly.

- The authors have recommended using commercial software such as "context-capture" from Bentley in lieu of their developed algorithm to enhance the system's accuracy for the captured photos.
- Detecting deviations that occurred to the as-planned schedule required developing numerous algorithms, and to that end, tasks were broken down to their constituent elements. Accordingly, accuracy of recognition was intrinsically linked with the level of dissection and the ability of trained classifier. However, the trained classifier succeeded in recognising only five out of the eight elements. Therefore, the authors recommended devoting additional efforts for future research to improve the detection algorithms.
- The progress status was updated and presented using colour codes; however, recreating construction progress as a colour coded system was also deemed unsuitable for both staff suffering from colour-blindness (Ware, 2004), and for black and white printing and faxing.
- The system relied heavily on manual intervention, wherein, manual feeding of the data acquired from site is the mainstay for interpretation of the progress in percentage terms for the work accomplished compared with the as-planned schedule.
- The authors did not mention how they dealt with occlusions in the photos collected from the construction sites.
- The system was designed to be automated. However, inputting the data into the system heavily relied on human intervention and additionally, the final judgment of the progress made is decided by the user based on their visual assessments. Accordingly, the system's outputs were subjective, prone to errors, and time consuming, moreover, the system's accuracy and reliability were doubtful.

All the above offered systems that are for either indoor or outdoor construction buildings. However, the following proposed system presented an automated monitoring system for longitudinal projects such as highways, pipelines, railways, etc. The system used satellite images, BIM and ***Geographic Information System (GIS)***.

3.12 Geographic Information System (GIS)

3.12.1 Historical glimpse of GIS

Mark *et al.,* (1997) reported the advent of GIS was in the early 1960s, supported by DeMers (2009) who stated that the first GIS computer map was developed by Roger Tomlinson in

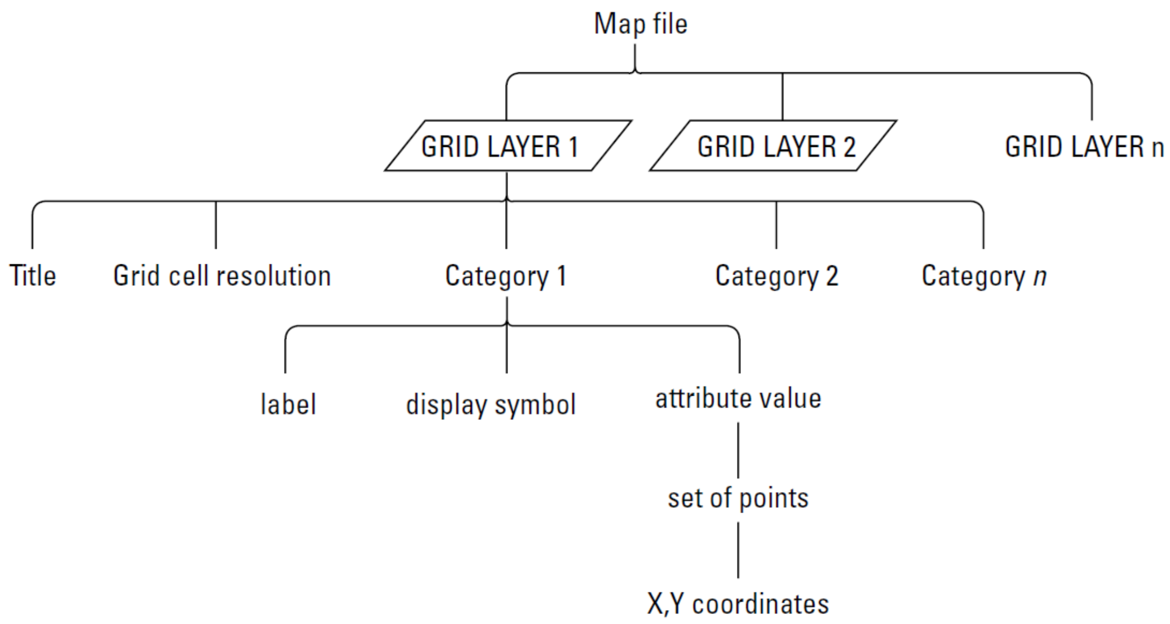
1960 in Ottawa, Canada for the federal Department of Forestry and Rural Development and that Dr. Roger Tomlinson is known as “the father of GIS”.

Later in the 1970s and 1980s the vibrant leadership of the USA created a paradigm-shift for the GIS advancements. Frost and Sullivan (1995) reported that the investment in GIS and its associated software and services hit $2 billion USD. The investment in and development of GIS reaped its benefits in the 1990s, when GIS was recognised as the critical factor in reviving academic geography. The 2000s witnessed tremendous advancements in computer, satellite, GIS software as well as the Internet, which assisted GIS to accomplish rapid spurts of growth to boom and achieve its peak by the late 2000s.

Accordingly, GIS is utilised in various industries such as forestry, glacier inventory studies, hydrology modelling, historical research, construction, mining, etc. Since the late 2000s, GIS software and applications facilitated data collection and interpretation (Walford, 2017).

GIS starts with data capture or entering the data in a digital format into the system for further processing, and this traditionally achieved through two basic methods. The first method is effectively a land survey and widely used for limited and small areas such as construction sites. This method utilises surveying instruments such as total station, laser scanning and close-range photogrammetry (Ben *et al.,* 2017). The second method is by remote sensing such as UAV equipped with camera or LS, in addition to the wider use of satellite in the case of studying countries, continents or the earth and like. Remote sensing collects data without any physical contact with the object and uses a wide range of sensors that differ according to the area being studied.

The GIS acquired data are layered as shown in Figure 3.14. Thus, GIS software used for interpretation of all the integrated layers to develop the final output which can be printed or presented for further use or to support decision makers.



Source: GIS for Dummies, reused with permission from Wiley Publishing

Figure 3.14: The layers of GIS data collection and integration

According to National Geography blog (2017) GIS is a computer system for capturing, storing, checking, and displaying data related to positions on Earth's surface. GIS can show different types of data on the same map, such as streets, buildings, and vegetation. This enables people to easily view, analyse and understand patterns and relationships.

The following research proposed a system that integrated GIS, satellite images and BIM, enabling the automatic comparison between the as-planned construction schedule and the actual progress for linear infrastructure projects.

3.13 Automated progress monitoring system for linear infrastructure projects using satellite remote sensing

3.13.1 Description of the case study

They tested their system on a railway project for the extension of the light rail transit (KLJ Line, formerly known as Putra LRT/LRT2) in Kelana Jaya, Kuala Lumpur, Malaysia. The project consisted of 510 piers, and 240 spans of precast box girder segments through 17.4 km and 13 stations. The nature of the project consisted of repetitive tasks in each unit for the whole length of the project. The main scope for the works was in four repetitive stages:

Stage 1: Site clearing and boredpile platform and activities

Stage 2: Pile cap construction

Stage 3: Pier works and pier head construction

Stage 4: Segmental Box Girder (SBG) launching and post-tensioning activities.

3.13.2 System architecture

The system's architecture is illustrated in the following Figure 3.15.

The system is designed to stream the data in four phases (data collection, data integration, retrieving data and data representation).

The prime components of the system consist of the following;

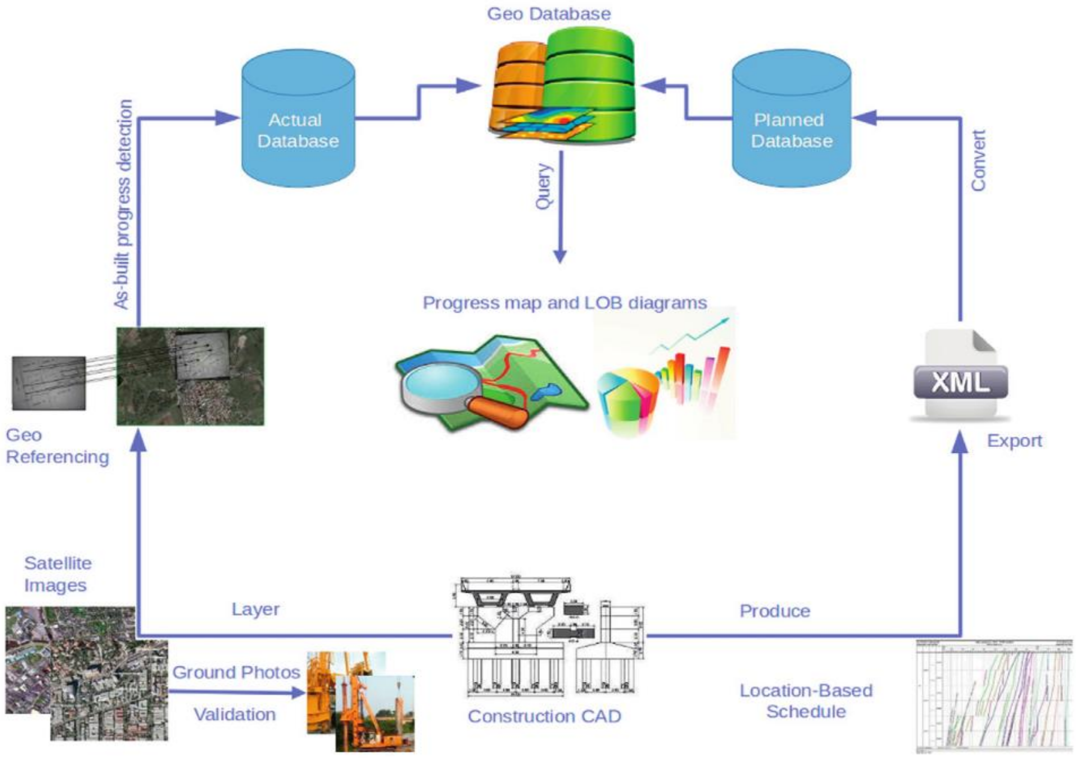
I. **Operating systems**: a platform that hosts all middleware tools such as the application server, database management server and web interface.
II. **Application server**: works as a store layer for hosting satellite images taken on different dates.
III. **Database management server**: saves spatial data in the form of tables.
IV. **Web interface**: consists of open source libraries to represent geographic data with generated charts and a map to visualise and report the as-planned and actual construction progress.

An automated comparison between the as-planned construction schedule and actual progress for the linear infrastructure projects has been accomplished in five steps as follows:

1. **Image co-registration:** the design of the system assumed; the main source of data was the satellite images. However, several satellite images were of poor quality and in the matching process were distorted due to the orbital direction, viewing direction and sun elevation. To improve the matching issues, spatial GIS coordinate translation between images were calculated and these translated parameters were used to rectify the distortion occurred to the images. In addition to the satellite images, site photos were captured manually and data from both sources were co-registered onto one single database.
2. **CAD design alignment:** all the construction elements were developed in 3D BIM models for easy representation of the coordinates, shape, size and orientations. In order to achieve easy alignment, the scale for all models was unified and all models were oriented to true north. Moreover, the site used its local coordinate system and accordingly, all the construction elements were referred to that local system. The local coordinate system was further unified and integrated with the coordinates that were used for the images captured by satellite. Ultimately, the BIM models and satellite images have the same coordinate system and they were perfectly aligned

and superimposed. To emphasise, each object in the satellite image was superimposed as a true representative of the BIM models.

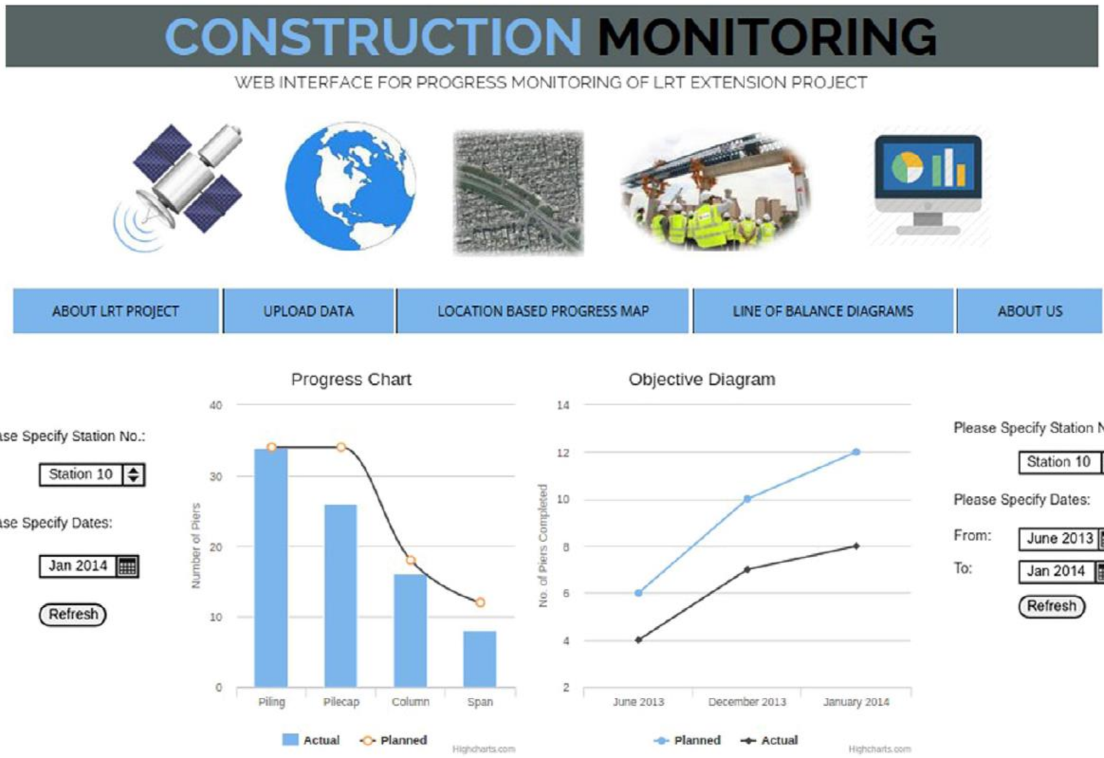
3. **Automated detection** of repetitive construction stages using image recognition algorithms: this stage sought to detect the actual construction stages for the 17.4 km length. Automatic detection was achieved by using algorithms that enabled the interpretation of images by visual characteristics such as orientation, pattern, size, shape and colour.
4. **Updating a spatiotemporal database:** this stage consisted of geographical coordinates for the project location and the date/time of data acquisition for the current construction stage. In this stage, the detected progress was cross checked against the previous sequence of construction tasks for a specific location. If the detected stage matched with the previous construction sequence, then it is considered as a successful identification.
5. **Validation process**: this step aimed to evaluate and test the accuracy of the system which was achieved by comparing the acquired results from the system against the actual progress extracted from the conventional manual progress reports. The manually developed reports were considered as actual reality that supplants the outputs extracted from the proposed system.



Source: Behnam et al., (2016, pp. 117), reused with permission from Ali Behnam

Figure 3.15: Development of the automated progress monitoring system

The results were displayed in the web interface that is illustrated in Figure 3.16, the web interface enabled users to determine the location for each construction element, and the as-planned and actual progress status using color-coded icons and a pop-up window. Moreover, the web interface was designed to visualise the progress charts and the images captured from the site.



Source: Behnam et al., (2016, pp. 125), reused with permission from Ali Behnam

Figure 3.16: Progress and objective chart

3.13.3 Benefits of the system

The system enabled automated measurements, web-based visualisation and documentation of the progress updates. Moreover, the system enabled automated generation and presentation of the overall project progress status which has accordingly supported the decision makers with the web-based monitoring system.

3.13.4 System limitations

- The Authors acknowledged that their system was incomplete, unreliable and lacking the ability to automate the estimation of the construction progress updates. Behnam et al., (2016), reported that "*The proposed system is a supporting tool to the conventional site monitoring practice which is not intended to replace the manual progress data collection*".

- Data acquisition from the construction site heavily relied on the manual capturing of site photos; these collected photos were paramount in validating the actual progress on site for comparing it with the progress, that is detected through satellite images.
- Ostensibly, using satellite for data acquisition is suitable only for longitudinal projects such as pipelines, roadworks, railways, etc. Indeed, the satellite remote sensors are located thousands of kilometres away from the earth which made it too difficult to capture images for small vertical projects such as buildings. Traditionally, most of vertical construction elements are occluded and require special design and settings for the satellite sensors to capture all the details of these elements.
- Typically, the satellite remote sensors have a significant width of field of view due to its extensive distance from the Earth, and accordingly, the captured images tend to encapsulate various unwanted objects. In simple terms; the captured images tend to include a vast number of objects other than the target construction objects.
- Furthermore, the captured objects are incredibly small due to the faraway position of the satellite remote sensors. Consequently, the required details for the construction objects are barely detectable.
- Despite several attempts to improve the resolutions for the satellite remote sensing, the resolution and accuracy were very low, which resulted in unreliable outputs for the small objects in the construction projects. Zie *et al*., (2008) claimed that, the accuracy of the collected data using satellite images depends on the spatial resolution which is usually low. Consequently, Benham *et al.,* (2016) failed to increase the spatial resolution without adding several processes which brought about a very complex system.
- In addition, using satellite for construction site data acquisition requires special permissions and additional costs compared with other technologies such as LS and photogrammetry. Consequently, it was difficult to acquire a streamlined data collection on a daily or even weekly basis, and as such the data in the case study was collected on only three occasions i.e. once in June 2013, December 2013 and January 2014. Therefore, there was no prompt progress update for the construction to support decision makers.
- Obviously, detection and analysis of the objects captured by satellite images tend to be a difficult task. In the same context, Blaschke *et al.,* (2014) affirmed that, using satellite to collect, analyse and manage of such construction data to support monitoring site activities for construction projects remains a big challenge.
- It is obvious the system heavily relied on continuous manual intervention to collect site photos, correct flaws resulting from the orbit-orientation, align the BIM model

with photos and validate the results with the ground-based construction progress reports, which remained the "ground truth of data".

- Finally, Zhang and Zhou (2004) established that, the satellite remote sensing technique is not suitable to acquire data for construction projects.

The challenge and complexity of monitoring construction progress has grabbed a great deal of attention from researchers, which has made it one of the most interesting research topics. Accordingly, researchers are continuously developing new systems by integrating various technologies. The following research has integrated photogrammetry, 3D point cloud model, machine learning, and 4D BIM model.

3.14 Historical glimpse of 4D BIM model

The literature review revealed that there is no documented history showing the development of the 4D BIM model.

However, the fourth dimension (4^{th}D or 4D) is not a new concept as this term was introduced in 1788 by Joseph-Louis Lagrange in his book "Mécanique analytique". Wherein, he proposed adding "*time*" as the fourth dimension for a better understanding of the performance by mechanical objects (Gabay, 1989). In 1827 by Möbius and 1853 by Ludwig Schläfli attempts were made to include the fourth dimension within several industries (Coxeter, 1973). In 1880, Charles Howard Hinton explained and demystified the 4D concept to researchers and different industry practitioners in his published research titled "*What is the fourth dimension*" (Rucker, 1980).

According to Minkowski (1909) the paradigm-shift that contributed to the popularisation and dissemination of the 4D concept, culminated in 1908 when Hermann Minkowski presented his concept of the space-time. In fact, Minkowski's work formed the basis of Albert Einstein's celebrated theory dubbed "*theory of special relativity*" (Fraassen, 1969).

Since then 4D has been used generally in many industries and with the advent of BIM the construction industry has been compelled to use 4D (Eastman *et al.,* 2011). Noticeably, software developers of BIM have considered the 4D BIM model as one of the fundamental tools to represent the construction object in spatial three dimensions in addition to its time's dimension.

3.14.1 Definition of 4D BIM model

The Royal Institute of Chartered Surveyors (2014, p.66) defined "4D BIM" as the model developed by the addition of time dimension to a 3D model and is also referred to as 4D planning or 4D simulation.

3.14.2 Machine Learning (ML) and Artificial Intelligence (AI)

3.14.2.1 Historical glimpse for ML and AI

ML is a subset of AI, and accordingly their development is interconnected. Although it has been found that ML was developed before 1950, reliable literature shows that Alan Turing, the mathematician and computer scientist who proposed the development of algorithms in 1950, is considered the "*father of theoretical computer science and AI"* (Herrero, 2013). Turing's research has pathed the way for subsequent scientists to harness their efforts for developing the new science.

In 1951, Marvin Minsky and Dean Edmonds invented the first AI machine (First Neural Network Machine) that was able to learn and interact according to the inputs (IEEE 2008). Later in 1957, Frank Rosenblatt invented a machine based on AI with the machine having the ability to simulate the human brain, to recognise or discard orders according to certain module-based algorithms (Seising, 2018).

In 1979, a brilliant student -*his name has not been mentioned in any literature*- at Stanford University invented a cart that was able to detect obstacles in the entirity of its surroundings. The cart was programmed based on knowledge of the surrounding objects collected from images and the cart succeeded in locating the objects in 3D to deduce its sensory motion to avoid objects (Moravec, 1983). Zadeh's contribution in 1994 created a paradigm-shift for the method of computation in the field of AI and ML. He proposed a new way that mimicked the human brain to deal and accept real life problems with a tolerance for imprecision, partial truth, approximation and uncertainty in an efficient and autonomous module called "soft computing" (Zadeh, 1994).

Momentus breakthroughs were achieved in the 2000s, with a multitude of AI developments. SIRI which was developed by Apple corporation in 2011 is such an example; an interactive AI that receives voice orders and interacts with those order, according to its pool of data which is based on a series of algorithms which search recommendations, the internet, phone calls, etc. Similarly, "Google Now" developed by Google in 2012 is able to perform similar tasks that Siri does.

In 2018 Google released its latest AI invention (Google Duplex) which is a more advanced version of "Google Now" and interacts and speaks like a human with its actual design being to imitate a human. Google Duplex has the ability to make appointments using the user's schedule and daily routine, such as to reserve a seat in a restaurant or book a room at the user's preferred hotel, and reschedule or cancel meetings, etc. (O'Leary, 2019).

3.14.2.2 Definition of ML

Indeed, the literature review resulted in a multitide of definitions for ML. However, the most widely used definition belongs to Tom Mitchell in his textbook titled "*Machine Learning*". According to Mitchell (1997), ML is about developing computer programs to interact automatically with the fed data based on series of algorithms and predefined patterns with the aptitude for continuous improvements from experience. Using a technical language this definition equates to: "a computer program is said to learn from experience E with respect to some class of tasks T and performance measure P, if its performance at tasks in T, as measured by P, improves with experience E".

The previous limitations encouraged Braun and Borrmann (2019) to publish their work. Their research proposed a system that sought to automatically compare the actual progress (captured images) against 4D BIM model (as-planned). Automated assessment of the construction progress status achieved when BIM elements were projected onto the captured images as shown in Figure 3.17 and Figure 3.18. For that end, the proposed system has utilised photogrammetry, 4D BIM, machine learning and 3D point cloud.

3.15 Research title: Combining inverse photogrammetry and BIM for automated labelling of construction site images for machine learning

3.15.1 System architecture

The aim of the proposed system is the automation of monitoring construction progress based on labelling the images collected from site using photogrammetry technology. Labelling site photos is realised by defining a polygon line around each object and associating a corresponding category with this label (refer to Figure 3.18). The system is explained in the following five steps (refer Figure 3.17).

Camera position: the system collects photos of the construction site using either cameras or UAV, provided that, each element is captured from at least two positions. The collected photos are used to construct the 3D point cloud model which is considered the as-built. The position for each camera is determined precisely and then fed into the developed algorithm to define the location for each element for conversion into (X, Y, Z) coordinate system.

4D process data and as-planned vs. as-built comparison: this process allows for identifying all elements that are expected to be constructed, and additionally, the auxiliary works such as scaffolding, and framework are identified in the 4D BIM. This step enabled defining the construction elements used for labelling columns, walls, slabs, etc.
Moreover, the main concept for comparing the as-planned of the 4D BIM versus the as-built is that it is developed from the 3D point cloud model and is unchangeable and fixed as-planned schedule.

Projection: the objective of this step is to enable visual inspection of the projected set of construction elements.

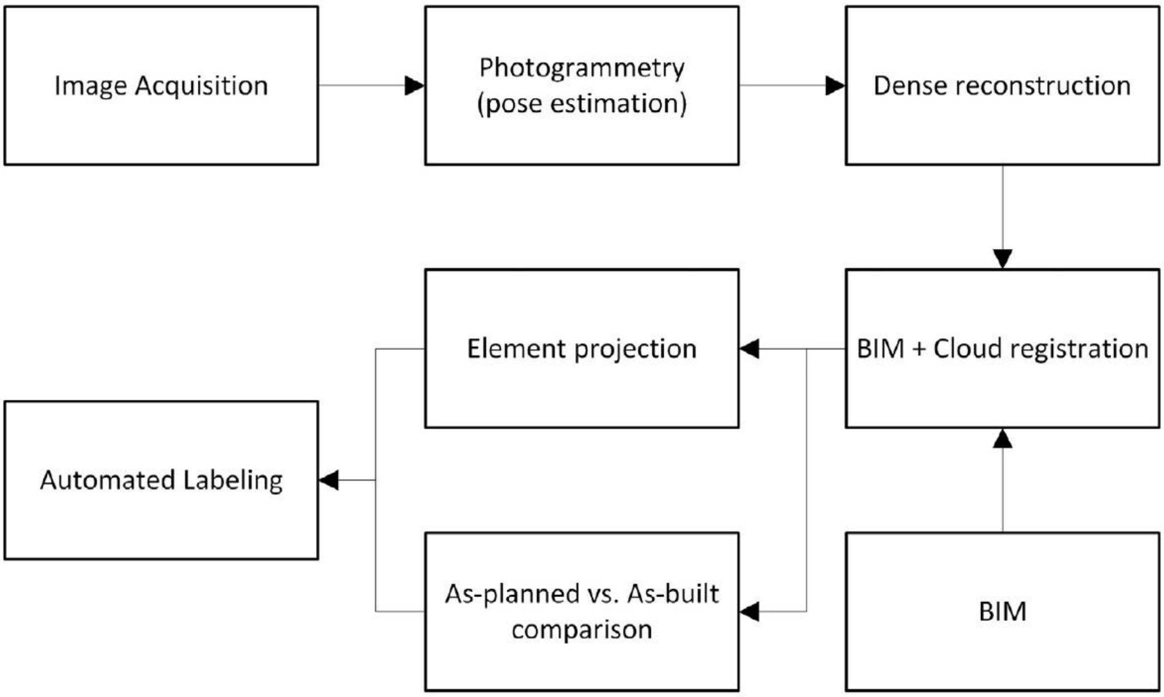
To enable true projection of each element from the 4D model to its representation on the captured image, an algorithm was developed to enable the transformation for the coordinates of the 4D model into the camera coordinate system.
This process enabled projecting the works as expected to identify the respective construction elements in the recorded image. In other words, comparing the as-built and as-planned in the previous step verified whether the elements had been finished, and then projecting the 4D BIM elements on the images Figure 3.18 according to the inspection dates. Furthermore, this process enabled visual recognition of the progress status.

In the event that the projection on the image from the 4D exists and the corresponding element is not available in the image, that meant this element is showing delays behind the planned schedule, as referred to in the three columns on the left in Figure 3.18.

Render model based on camera position:

The aim of this step is to present a rendered model to visualise the non-occluded elements. This is achieved by a developed algorithm that projected all the visible construction elements based on the camera positions.
Generating labels for machine learning:

In the first step, the authors developed algorithm based-machine learning from 1300 photos to train a classifier for the auxiliary works (i.e. shutter, scaffolding, machine, etc.) and permanent works (i.e. column, wall, beam, slab, etc.).



Source: Braun and Borrmann (2019, pp. 5), reused with permission from Alex Braun

Figure 3.17: The workflow of the proposed system

Source: Braun and Borrmann (2019, pp. 9), reused with permission from Alex Braun

Figure 3.18: Projection of BIM elements onto the captured photo

3.15.2 Benefits of the developed system

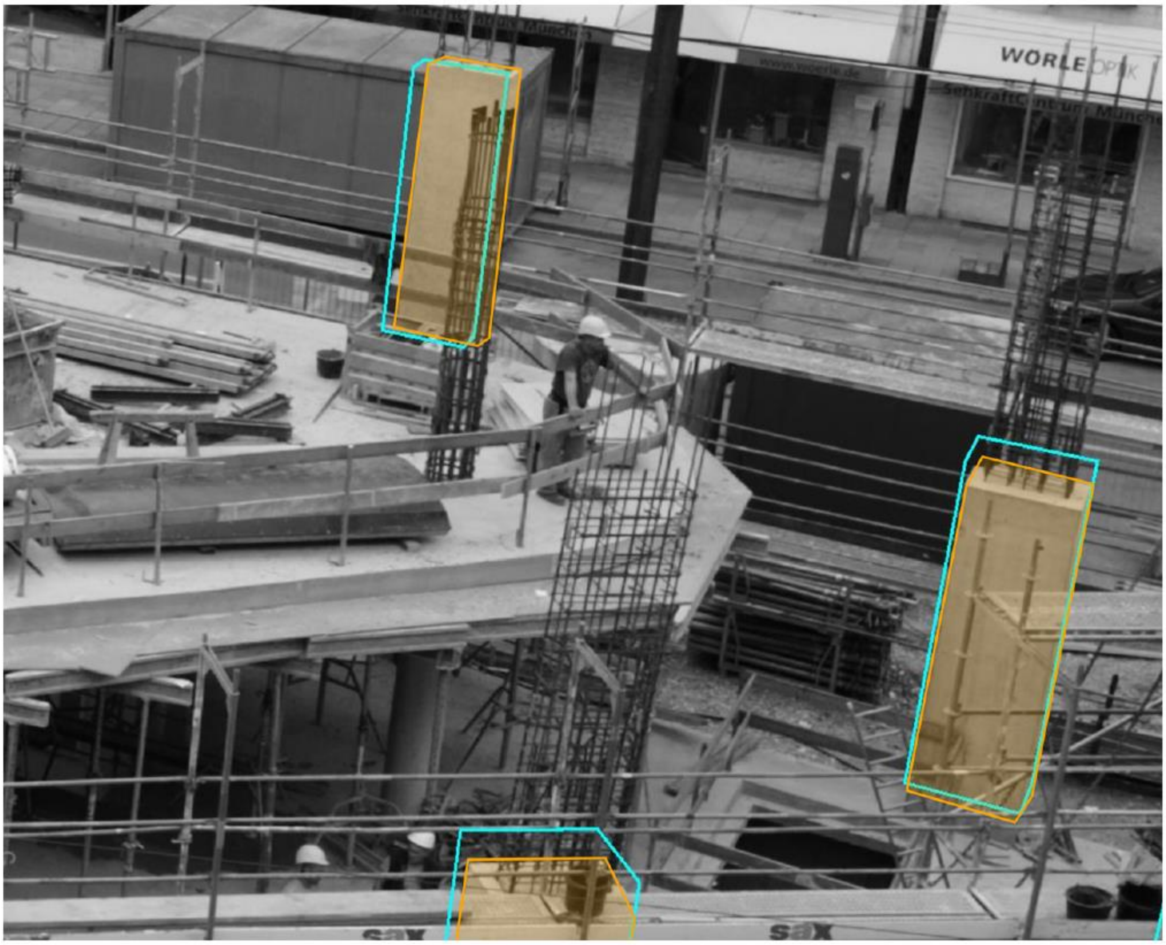
The system proposed a labelling system based on real construction elements that can be used for future projects to enable easy recognition of the construction progress. Moreover, the developed algorithms reduced the time required for labelling the construction elements from 100 hours to 20 minutes.

3.15.3 Limitations of the system

Although the authors have proposed a novel method for monitoring the progress for construction projects, the system has been faced with the following limitations:

- Recognition of progress status was done visually, as the system did not use any dashboard to present the overall progress status or the element's status.
- The system was not designed to support decision makers with regular updates of the progress status, which means the project manager was not receiving daily or even weekly updates for the progress to be able to recognise the project status and delays.
- The system was developed on an unrealistic assumption of a static construction schedule. The construction schedule inevitably experiences continual change to respond to any arisen and unforeseen variation such as, claims, and change orders or the like.
- The system was designed to report only the completed activities. However, partial completion of the construction elements were not considered as the developed labelling system was developed for only the completed element. This resulted in misjudgment on the activities, whereas, according to the system the progress of the activity is 0% even though it is 90%.
- The system requires an operator in order to visualise, judge and infer the progress status.
- Visual verification was required to ensure the precision of the projected elements from the 4D BIM model to the image.
- As the construction of the case study site had not started at the time of the construction start date, photos from other sites were used to train the classifier the algorithm. Accordingly, the accuracy of the labelling algorithm was less than expected, mainly because the construction elements for the site wherein the 1300 photos were collected often differed from the case study.
- The system used 1300 photos collected from other sites to train the classifier algorithm to enable labelling the elements. Consequently, the time required to train the algorithm was laborious and time consuming.

- The authors considered the system as a local system valid only in Germany and would require further development to be considered suitable for use in other countries, mainly because the labelling algorithm was developed based on photos pertaining to construction elements and auxiliary works that may differ in other countries. Consequently, the algorithm cannot be used, because it will fail to recognise the auxiliary works and accordingly will fail to label the construction elements.
- Although, the labelling algorithm reduced significantly the recognition time, yet, training the algorithm for the first time heavily relied on the human intervention to select the suitable photos which again is a subjective judgment and usually prone to errors. Indeed, this step defines the accuracy for all the consecutive steps and processes and ultimately the entire system.
- The automatically generated labelling algorithm failed to correctly label construction elements as shown in Figure 3.19, wherein the projected elements deviated from the actual construction elements due largely because the inner walls were not visible from enough viewpoints.
- The best accuracy achieved for the proposed system was reported as 91.7% which is not a satisfactory or reliable level of accuracy for decision makers to make informed decisions in the construction industry; specifically, for prestigious or mega projects as the margin of error that is more than 8% in this case, could mislead decision makers to make wrong decisions that could result in a loss of hundreds of thousands sterling pounds.



Source: Braun and Borrmann (2019, pp. 10), reused with permission from Alex Braun

Figure 3.19: Flaws due to automatic projection of BIM elements onto the captured photo

The literature review revealed that, the proposed systems suffer from inaccuracy and unreliability, are cost-ineffective and subject to lack of objectivity and prone to errors, with a heavy reliance on human interventions and with no ability for instantaneous notification of delays.

3.16 Delays detection through monitoring construction activities using cloud-based BIM model (mobile BIM)

The realised limitations have motivated software developers to produce a semi-automated cloud-based system based on the BIM model that is available in the cloud server to collect data from construction sites using PDA such as tablets or smartphones which are called mobile BIM (Koseoglu and Nurtan-Gunes, 2018).

According to Omar and Dulaimi (2015) the inspector is required to visually check the actual activity and on the-spot update the construction status using a unique ID for each task that is predefined in the BIM model. Once the inspector checks the task, the hand-held device automatically introduces the pre-prepared check-list that is suiting the recognised task and acordingly, the inspector required to manually fill-in the check list on-site.

This system allows the inspector to narrate and review all the previous tests i.e. the test results or the required tests, the project specifications, review the construction method statements, review the previous approvals or comments, all the required details are usually available on-site for each task under a unique ID via the developed BIM model.

In order to complete the inspection and update the progress to detect the delays, the inspectors are required to send the collected data via the internet that is connected to the PDA devices to the cloud and then the planning engineer is required to use the available data to update the as-planned schedule to figure out the project status and delays (Koseoglu and Nurtan-Gunes, 2018; Omar *et al.,* 2018) .

Obviously, the mobile BIM still relies heavily on the inspectors to visually inspect and manually insert the construction site updates, which is not only subjective but also unreliable and prone to errors (Omar *et al.,* 2018) . Consequently, this system lacked the instant detection of delays, reliability and accuracy (Kimoto *et al*., 2005; Kim *et al.,* 2008; Omar and Dulaimi, 2015) .

Therefore, these limitations have inspired the researcher to propose a system within this research study which is fully automated and seeks to develop an original, close-range photogrammetry-based approach for monitoring the construction progress that is able to detect and report the delays instantaneously via SMS and emails on a daily basis to the relevant project managers to support decision making.

3.17 Chapter Summary

Despite various initiatives and efforts, the comprehensive literature review revealed that to date there is no approach/system that has successfully automated the monitoring, analysing and controlling of construction site activities to detect instantly any delays once occurred. This is intrinsically linked with the prevailing monitoring systems which suffer from various inefficiencies that fail to detect potential delays. In addition, they do not have the ability to collect accurate and reliable data to reflect the correct as-built site progress status.

This thesis proposed an automated system which is presented in chapters 5, 6,7,8, and 9. Whereas, chapter 4 outlines the research methodology.

Chapter 4-Methodology and research design

4.1 Introduction

The purpose of this chapter is to select the most appropriate design for this research study. To that end, the most commonly used research approaches are introduced and discussed; this will allow justification of the most suitable research method and design to achieve the research objectives. This chapter introduces different types of research philosophies, methodologies, strategies, time horizons and techniques and procedures for data collection. Furthermore, at the end of each section, justification will be given for the selection made.

4.2 Research methodology

According to Saunders *et al.,* (2009), the success of the research study correlates with the most appropriate selection of research design including philosophy, methodology and strategy that offers solution for the research problem.

4.3 Research philosophy

According to Saunders *et al.,* (2009) research philosophy is the belief assumed by the researcher based on how they see the world. The literature study shows that there are four types of research philosophies, which are "*positivism, realism, interpretivism and pragmatism".*

Positivism philosophy: this research philosophy is based on a perspective of natural science, which focuses on observing phenomenon, facts and value-free way. Positivism typically involves a large sample of quantitative data and statistical hypotheses for testing theories with highly structured and measurable data. Positivism is referred as the scientific method, as the main driver for testing and validating theories is data analysis and findings not the researcher's values (Saunders and Tosey, 2013).

According to Creswell (2009) positivism philosophy is built on four pillars which are ***determination, reductionism, empirical observation and measurement and theory verification*** as further explored below:

1. **Determination:** positivism is deterministic which relates to the causes determining the outcomes/effects, and therefore, those causes must be identified and assessed, through *experimental testing*.
2. ***Reductionism:*** it is notable that researchers who adopt positivism tend to reduce the research idea into set of measurable variables that comprise of the hypotheses and research questions.
3. ***Empirical observation and measurement:*** whereby the function of the researcher in collecting data and subsequent analysis is confined to vigilant observations and numerical measurements with complete objectivity of the realities exists in the world.
4. ***Theory verification:*** the positivist researcher starts with a theory that needs to be either verified and accepted or refuted and rejected in accordance to certain laws and axioms that govern the world.

Several researchers have stated that positivism is not a suitable research philosophy for studying human feelings, behaviours or actions, mainly because this type of knowledge is subjective and usually employs qualitative approach for data collection (Creswell, 2009; Phillips and Burbules, 2000; Saunders and Tosey, 2013).

The positivism philosophy is not appropriate for this research, as this research study involves human opinions and insights to assist the researcher in visualising the development of the prototype and to further measure the effectiveness of the developed system.

Realism philosophy: this thinking is based on the belief of an existence of reality, which is independent from an individual's perception that is made up of tangible and immutable structures. The individual is born into and living within a social world that has its own postulates whether humans are aware or not of its nature. This is a reality not created by individuals; it exists even before the creation of mankind. (Burrell and Morgan, 2005). In a nutshell, realism is about the postulates that surround individuals who may or may not be aware of its intrinsic nature. However, individuals interact with these tangible elements as immutable realities, as the human does not have the power or the authority to control any of its features or structures.

Clearly, realism philosophy contradicts human sovereignty. Accordingly, it is not suitable for this research study, as this research requires human input for the development of an automated system that enables the developer to control and change its features.

Interpretivism philosophy: interpretivism relates to studying social phenomena in its natural environment; it is concerned about people rather than objects. Unlike positivism, it considers people's emotions, understandings and feelings are functioning in definite circumstances at a specific time for the researched topic (Saunders and Tosey, 2013). According to Creswell (2014), interpretivism is typically seen as an approach used for qualitative research. Burrell and Morgan (2005) view interpretivism as the individual's consciousness of the fundamental nature of a social world at the level of a subjective experience. Flick (2006) perceived interpretivism philosophy as the best approach for interpreting human behaviours and actions in the context of social studies such as politics, economics, and education.

Although, this research involves the human experience to evaluate the system, interpretivism philosophy is not the suitable approach, primarily as it involves the development of an automated system, dedicated to a specific purpose that will be used by selected users, only within the construction industry.

On the other hand, the adoption of a paradigm that is based on a single viewpoint will not result in a holistic portrayal of the research problem and will often result in overlooking alternative realities (Saunders and Tosey, 2013).
Evidentially, adopting one of the above-mentioned philosophical approaches will result in the research being undertaken from a single perspective which culminate in gaps and weaknesses when conducting the research.

Pragmatism philosophy: according to Patton (1990) and Burrell and Morgan (2005) pragmatism is a problem-oriented paradigm which aims to provide practical solutions for identified problems. Accordingly, pragmatism philosophy was developed largely to fill the gaps found in the other research philosophies.
Several researchers affirmed that, pragmatism is not committed to using only one approach; it tends to apply mixed approaches, which allows more flexibility for the researcher to attain advantages from both quantitative and qualitative approaches (Flick, 2006; Saunders *et al.*, 2011; Creswell, 2014).
Accordingly, the researcher is free to select the most suitable approach that corresponds to their research objectives, either quantitative or qualitative or a mix of both approaches.
Several researchers have emphasised that pragmatism is the most fitting research philosophy suitable for investigating and validating the engineering science and information systems research (Hirschheim, 2000; Baskerville and Myers, 2004; Agerfalk, 2010).

The practicality of the pragmatism philosophy designates it as the most suitable approach for this research, principally due to its flexibility in allowing the adoption of a mix of qualitative and quantitative approaches which are required for conducting this research. Whereby, qualitative inquiry will enable collecting the data from the users to recognise the weaknesses of the proposed system for further improvements, however, the quantitative enquiry will allow evaluating and verifying the effectiveness of the developed system.

4.3.1 The adopted research philosophy

The above discussion explicitly demonstrates that, the research problem and objectives do not apply to ontological knowledge or pure epistemological knowledge and accordingly, it does not comply with either the realism, positivism or interpretivist research criterion.
However, this research fits perfectly with the pragmatism philosophy, mainly because it tends to be characterised as an issue-driven approach to propose practical solutions for the research problem. This adopted approach is supported by Chynoweth (2009), who stated that pragmatism tends to be the most appropriate philosophy for built environment and construction management research. Moreover, Onwuegbuzie and Leech (2005) claimed that, it has been observed that graduate students tend to adopt the pragmatism approach as it provides them with more freedom for data collection and analysis.

4.4 Research design and processes

4.4.1 Design science

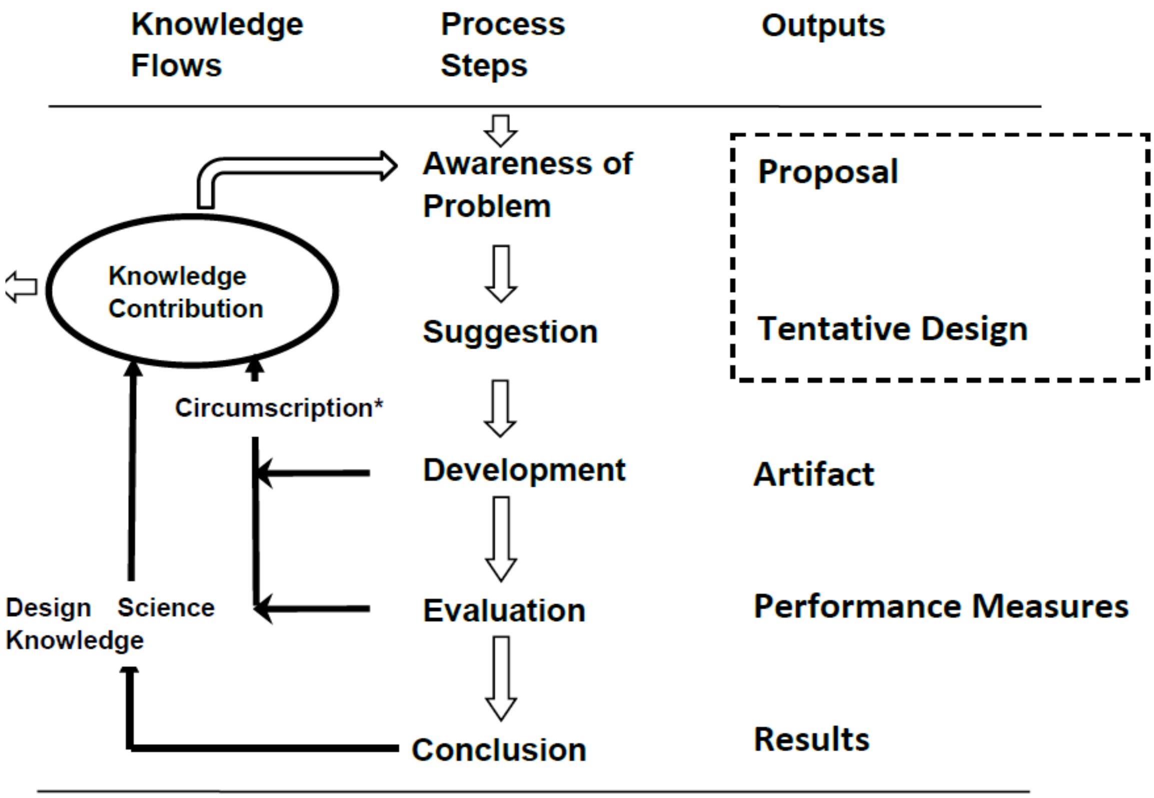
Since the aim of this study is to develop an innovative and new fully automated system to detect project overruns and inform decision-makers by giving them timely and accurate information to detect delays, the research design and processes should be carefully selected to assist the researcher in responding to the research aim and objectives.
To that end, an extensive literature study was conducted, which ultimately shows that Design Science (DS) is considered the most suitable research design for guiding the researcher, to appropriately develop the sought system.
According to Hevner *et al.,* (2004, p.77) design science creates and evaluates artefacts intended to solve identified organisational problems. Simon (1996) reported that, design science creates a paradigm-shift in the engineering research for developing innovative and novel artefacts.

Interestingly, there is a great deal of consensus amongst researchers that the ‘‘logical’’ procedures stipulated in design science, enables the proposal of novel artefacts to resolve recognised problems (March and Smith, 1995; Hevner *et al.,* 2004; Hevner, 2007; Peffers *et al.,* 2007; Wendler, 2012). The vast majority of researchers have considered design science a research strategy; however, some researchers consider design science as a super-methodology that contains sub-methodologies (Nunamaker *et al.,* 1991; Lee and Chuah, 2001).

However, this research study considers design science as a research strategy that outlines the research design and processes and embraces standard processes that will be detailed hereunder.

Design science has several definitions, and this may be attributed to the fact that each researcher investigates it from different perspective. Hevner *et al.,* (2004) defined design science as a coherent research paradigm seeking to extend the boundaries of human and organisational capabilities by creating new and innovative artefacts intended to solve identified organisational problems. This definition concurs with Denning (1997) and Tsichritzis (1998) who considered design science as a research strategy consisting of standard processes that seek to create innovations through the deployment of technologies for improving current practices and technical capabilities. According to March and Smith (1995) design science is a technology-oriented research paradigm that seeks to create inventions that serve and ease human life. Indeed, design science is fundamentally a problem-solving paradigm (Hevner *et al.,* 2004), that enables the development of innovative solutions for resolving the research problem (Simon, 1981).

According to Vaishnavi *et al.,* (2004) design science research, typically contains five standard processes (i.e. awareness of problem, proposal, development, evaluation and conclusion) as shown in Figure 4.1.



Source: Design science research in information systems (2004, p.11), used with permission from William L Kuechler

Figure 4.1: Design science research process model (DSR cycle)

Traditionally, design science research efforts get under way once the researcher has gained awareness about the research problem (Dresch *et al.,* 2014). The five standard processes of design science research are detailed hereinunder.

- **Awareness of problem**: awareness of the problem is a fundamental process in design science research, which tends to emerge from the practical experience and new developments in the industry. However, studying a specific discipline may lead to recognition of a problem pertaining to the researcher's field of study. Design science research is interested in problems that require the development of new artefacts and innovations. Yet, for the problem that requires only explanations without the development of an artefact or innovative solution; design science research is not the suitable choice (Vaishnavi *et al.,* 2004).

  Design science research is pragmatic in nature due to its clear contribution to the application environment (March and Smith, 1995; Hevner *et al.,* 2004). Typically, this profound study leads to thorough awareness of the problem in addition to deeper knowledge of hi-tech developments, and accordingly, the ***output*** of this process is an *initial proposal* for a new research effort (Vaishnavi *et al.,* 2004, p.12).

- **Suggestion:** This process starts after the *initial proposal*, has been developed, wherein the researcher's creativity is a fundamental prerequisite to propose a novel solution for the recognised problem using existing or by developing new technology that creates a functional paradigm shift. The tentative design of the proposed prototype is derived from the researcher's knowledge and experience which is an integral part of the *proposal*. Indeed, both processes (i.e. **Awareness of problem** and **Suggestion**) are interchangeable, wherein, if the suggested prototype, following the investment of considerable efforts was unlikely to provide a workable solution; consequently the researcher must discard the prototype (Vaishnavi *et al.,* 2004), and consider alternative solutions which will inevitably require enriching their knowledge, that is, back to the first process. The final ***output*** of this process is a *viable suggestion*.
- **Development:** in this process, the tentative design will be developed and implemented to create the artefact. The developed artefacts could be a new concept, model, process or physical instantiations (March and Smith, 1995; Hevner *et al.,* 2004; Gregor and Jones, 2007). Where a tentative design involves development of an algorithm, proof of the accuracy and validity of the algorithm is required. Vaishnavi *et al.,* (2004) established that, the artefact novelty is implicit within the tentative design that is developed in the second process (i.e. **suggestion**). However, the development stage encompasses ***testing the concept of the prototype*** in a *real-life case study*.
- **Evaluation**: several researchers emphasised that the evaluation process is a crucial part in the research process and specially for practical research. Remarkably, it is the evaluation process that distinguishes design science research and makes it superior to other research paradigms, mainly because they lack the evaluation stage (Nunamaker *et al.,* 1991; Vaishnavi *et al.,* 2004; Hevner *et al.,* 2004; Dresch *et al.,* 2014).

  In this part the functionality and successful measure of the developed artefact are verified, validated and evaluated against criterions that are usually defined in the first stage alongside with the proposal or tentative design (Vaishnavi *et al.,* 2004; Venable et al., 2016). Typically, engineering systems must be tested and validated in a real-life case study to ensure viability and usability of the developed system (Saunders *et al.,* 2011).

  As a result of the evaluation, if deviations are found, thorough investigation should be conducted to understand the root causes of these deviations. All the collected data is subsequently analysed and fed back into the process with additional feedback to form a revised proposal that overcomes the previous unsound results. (Vaishnavi *et al.,* 2004). The expected ***output*** after starting over is *an evolved proposal* that overcomes the recognised challenges which have resulted in an underperforming artefact.

  However, for the successfully validated artefacts, a revolutionary solution is brought about to resolve the research problem and influence the industry.

- **Conclusion:** Traditionally, the end phase of any research effort is the conclusion that presents the findings of the research. The researcher concludes with the findings to showcase the utility of the developed artefact in case; the research and development efforts have accomplished their objectives. Conversely, in the case where the developed artefact has failed to achieve its objectives, the researcher will investigate and present the root causes of the failure for further studies (Vaishnavi *et al.,* 2004).

  It is worth mentioning that, Hevner *et al.,* (2004) added an additional process, the sixth process, "*communication*"; communication was considered a complimentary process whereby the researcher shares and disseminates what they have accomplished to enrich others knowledge. Indeed, the small arrow at the far-left side of the above Figure 4.1 implicitly referred to communicating the research, as a knowledge contribution as illustrated.

4.4.2 Rational for the selection of the design science

Design science driven by the desire to develop a novel artefact to resolve a field problem, rather than offering explanations for the problem without development of a solution, is more suitable for the researchers who have actually experienced the effects of the research problem in the field (Gregor and Jones, 2007; Sein *et al.,* 2011). Moreover, the developed solutions are in line with the design science and are artefacts based on pragmatic validity (Figueiredo and Cunha, 2007).

Ultimately, the components of the proposed system (i.e. the artefact) will be developed from software and hardware which affirms the right choice for the design science. Hevner *et al.,* (2004, p.77) asserted that design science is inseparable from Information Technology (IT) which enables the creation and evaluation of artefacts intended to solve identified organisational problems within construction management research.

Increasingly, most of the research with similar objectives are widely adopting the standard processes of the design science research paradigm via the case study approach for testing and validating their developed systems (El-Omari and Moselhi, 2008; Ibrahim *et al.,* 2009; Roh *et al.,* 2011; Behnam *et al.,* 2016; Omar *et al.,* 2018; Braun and Borrmann, 2019).

4.5 Methodological choice

Methodology is defined as a system of principles, practices and procedures applied to a specific branch of knowledge (DM Review, 2007). And hence, selection of the appropriate research methodology is crucial as it affects the entire research study, starting from the theoretical concepts and extending to include data collection and analysis that enables solutions to be developed for the research problem (Wedawatta *et al.,* 2011).

The adopted research philosophy together with the research problem and objectives assist the researcher in choosing a methodology approach for data collection and analysis which can either be a *mono method,* or *multi* or *mixed methods*.
Denscombe (2010) stressed the importance in selecting a research method that enables the researcher to challenge the research problem.

Smith and Heshusius (1986) and Howe (1988) claimed that, to collect the right data and conduct rigorous analysis, quantitative and qualitative should not be mixed but that the researcher must adopt mono-method, either mono-quantitative or mono qualitative. Conversely, several researchers have refuted these earlier claims and stressed that, mono-method research is the biggest threat to the advancement of research (Onwuegbuzie and Leech, 2005; Fellows and Liu, 2008; Saunders *et al.,* 2009). Instead, selection of the research methodology should not be predefined; but must be selected based on prerequisite criterions. It should be the methodology that enables the researcher to collect and analyse the data to propose a solution for the research problem.
According to Saunders and Tosey (2013) there are several types of the research methodologies such as *mono method quantitative, mono method qualitative, multi-method quantitative, multi-method qualitative, mixed method simple and mixed method complex*, which are detailed below.

Mono method quantitative: this is a single technique dedicated to data collection only adopting a quantitative approach. In this approach data is in numerical form and only quantitative techniques are utilised to analyse the data (Azorín and Cameron, 2010). Traditionally, quantitative approach starts with a hypothesis or hypotheses that needs to be tested after the data collection and analysis and where these hypotheses can be supported or rejected (Creswell, 1994).

Fellows and Liu (2008) claimed that the mono-quantitative method is the best research method for addressing research questions pertaining to the "*how questions*". Moreover, it is a suitable approach for conducting empirical investigation of phenomena using statistical and mathematical calculations. In this context survey and experiments are the prominent tools utilised (Saunders *et al.,* 2009).

Conversely, the proponents of this approach claimed that, the findings are reliable as the human subjectivity is averted and accordingly, the results are objective (Amaratunga *et al.,* 2002 and Denscombe, 2010).

In fact, the mono method in general and the quantitative mono method in particular have been criticised by Bryman (2004) who claimed that, the accuracy and reliability of the findings are significantly affected by the limited sampling techniques and as such data availability. Moreover, that is loses the distinction of human views and evaluations.

Obviously, mono method quantitative is not a suitable method for this research study, mainly because human insights, evaluations and views are paramount to evaluate the effectiveness of the developed system.

Mono method qualitative: Commonly the limitations of the quantitative method tend to be the main driver for using the qualitative method (Flick, 2006). The qualitative method assumes the prior development of the conceptual theory, and accordingly, the qualitative method enables testing, discovering and developing theories empirically (Flick, 2006; Saunders *et al.,* 2009). Unlike the quantitative method, the qualitative method revolves around meaning, expressed through words which enriches the subjectivity of the research and consequently, the data analysis is a result of insights and views of the participants (Naoum, 2013).

The mono method qualitative employs various methods of data collection, such as spoken words, which is so called verbal data collection and this type of data is often collected via face-to-face interviews, narratives or focus groups. The mono qualitative method also uses observations, case studies, ethnography, photographic visual data, films and recoded videos (White, 2000; Flick, 2006; Peffers *et al.,* 2008 Saunders *et al.,* 2009; Naoum, 2013).

Although, this method has been widely adopted as a research method, in particular, for social science research, it has also been subject to criticism from several scholars such as (White, 2000; Bryman, 2004; Fellows and Liu, 2008; Naoum, 2013) who claimed the following weaknesses:

- The accuracy and reliability of the findings are intrinsically linked, where data collection involves interviews, with the selection of a true sample of interviewees.
- The collected data will be subjective as it is based on interviewees or observers' viewpoints.
- It is difficult to repeat the data collection, as it is often undertaken with busy people.

- There is no structured procedure for data collection; it is based on the researcher's viewpoint and modus operandi.
- Generalisation of the findings are dubitable, as the scope of the research is often determined by the interviewees and limits of the research scope.

Furthermore, according to Flick (2006) the ‘mono method qualitative’ is a single technique that utilises only one qualitative approach for data collection and analysis, therefore, its use is limited to social science research.

Accordingly, the ‘mono method qualitative’ is not suitable for this research study, mainly because this study requires both a qualitative approach to collect data from construction industry professionals, but also a quantitative method to evaluate the effectiveness of the proposed system.

Multimethod quantitative: refers to using multiple quantitative methods for data collection for the same research, for example, a questionnaire and structured observations, and then analyse the aggregated data statistically to present the findings (Saunders *et al.,* 2011).

Multimethod qualitative: refers to using two or more qualitative methods for data collection, for example using a face-to-face interview and a case study, and then as for the last method analyse the aggregated data to present the findings (Saunders *et al.,* 2011).

Multi and mixed research method: it is clear the research that adopts a mono-method, either quantitative or qualitative, will suffer from a wide range of limitations that will frustrate the efficacy of the research findings. Accordingly, integrating quantitative and qualitative in the form of a multi- or mixed method proposes to bridge these limitations of the mono methods (Onwuegbuzie and Leech, 2005; Creswell, 2009; Saunders and Tosey, 2013). This claim is asserted by Bryman (2007) who emphasised that, mixed research methods offer opportunities that mono-method research does not. Bryman (2007) and Creswell (2009) considered the multi research method as a synonym of mixed research method.

According to Azorín and Cameron (2010) and Saunders *et al.,* (2011) researchers use quantitative and qualitative methods concurrently or sequentially for data collection and the associated producers are used for analysis. Several researchers realise that mixing the quantitative and qualitative methods is the most appropriate approach for most research studies, mainly because it allows the advantages of both approaches whilst avoiding their limitations (Onwuegbuzie and Leech, 2005; Creswell, 2009; Saunders and Tosey, 2013).

Mixed-method approach: in this method the research could start with a qualitative approach of data collection such as a focus group to enable a broad understanding of all possible persuasive factors and then use quantitative data collection, such as an online survey to determine the relative frequency and/or importance of these factors. Data collection and analysis using quantitative and qualitative are performed separately either concurrently or sequentially (Creswell, 2009; Saunders *et al.,* 2011). According to Creswell (2009) there are four main methods that fall under the mixed method approach as outlined below:

- **Convergent parallel mixed methods:** this is a form of mixed method, whereby data collection employs quantitative and qualitative methods concurrently, and the collected data from both methods are integrated to provide a more comprehensive analysis. The analysis assimilates the information from both methods to present the research findings.

- **Explanatory sequential mixed methods:** in this method the quantitative method is utilised for data collection and analysis and based on those initial findings the researcher then employs data collection using the qualitative method. It is deemed explanatory as the results of the quantitative analysis are further explained by qualitative data analysis. Furthermore, it is sequential process as the qualitative method starts after the completion of the quantitative method ends (end to start). This method is used primarily for quantitative orientation research that requires statistical analysis, and therefore starts with the quantitative method followed by the qualitative method. This method has suffered from some criticisms since the quantitative results can be difficult to explain qualitatively on occasion (Flick, 2006).

- **Mixed method complex**: In this method data collection could start with either quantitative or qualitative; where the research begins with a quantitative approach for data collection, the collected data will be analysed qualitatively and vice versa. In brief, the data will be collected using a quantitative or qualitative method and will be analysed following to qualitative or quantitative, respectively. This method has also faced several criticisms similar to the last approach, whereby, collecting data using one approach can be difficult to analyse using the alternative approach.

- **Exploratory sequential mixed methods:** this method commence with a qualitative approach for data collection to explore the interviewees' perspectives and this data is then analysed qualitatively, and the findings will be the provide the basis for starting the quantitative method. The questionnaire for collecting quantitative data are developed based on the findings from the initial qualitative research, to define the sample size and the variables that need to be explored. It is deemed exploratory the quantitative approach investigates and delves deeper to explore the variables of the research study based on the findings from the qualitative method.

4.5.1 The adopted research method

The designated 'pragmatic' research philosophy together with the research problem and objectives led the researcher to select the *mixed method approach*, as pragmatism and mixed approach are intrinsically linked. Creswell (2009, p. 67) affirmed that, adoption of pragmatic paradigm mandates the use of the mixed research method.

Accordingly, the *exploratory sequential mixed method* was found to be the optimal choice of data collection, largely due to the exploratory nature of the initial qualitative approach; listening to the participants thoughts, and thus allowing the development of potential solutions. Accordingly, the exploratory method is the optimal choice especially as it fits the design science process for developing a new concept and novel solution.
The theoretical solution derived from the qualitative data analysis will be the basis for developing the prototype of the proposed system; the prototype will be tested in a case study (qualitative method). Face-to-face interviews will be conducted with the users of the prototype to evaluate and verify the effectiveness of the developed prototype.

Finally, an online survey will be administered to a representative sample of potential end-users of the system to assess the effectiveness of the final version of the system. According to Wieringa (2014) a quantitative method-based survey is the most conducive approach to validate technological systems developed in the field of engineering science.

4.6 Research strategy

Research strategy refers to the overall direction of the research including the process by which the research is conducted to collect the data (Remenyi *et al.,* 2003; Wedawatta *et al.,* 2011). Saunders *et al.,* (2009) considered the fundamental criterions for selecting the appropriate research strategy is the one that considers the research objectives, the available data pertaining to the research topic, the available resources and time allowed for the research.

Obviously, there are several research strategies, yet the most commonly used ones are *experiment, survey, case study, ethnography, action research, grounded theory, and narrative inquiry* (Collis and Hussey, 2009; Saunders *et al.,* 2009; Wedawatta *et al.,* 2011). The following outlines these most commonly used research strategies:

- **Experiments**: 'experiment' is the main research strategy utilised to conduct explanatory or causal inquiries and is chiefly associated with positivism and pragmatism research (Saunders and Tosey, 2011; Yin, 2017). According to Schell (1992) the successful experimental research strategy, relies on replication, causation, and objectivity to study the relationships amongst the investigated variables. Experiment strategy absolutely suits researchers that manipulate behaviour directly, precisely, and systematically, as it is basically conducted in laboratories wherein the experiment usually focuses on the variables under testing, while other variables are controlled (Fellows and Liu, 2008; Yin 2017). Obviously, experiments tend to be the first choice for natural scientists and widely used by medical researchers (Fellows and Liu, 2008; Kumar, 2011).

  Although, 'experiment' features rigorous control on variables, it has no control on the experimental duration, as some experiments require several years for completion (Kumar, 2011).

- **Survey:** the 'survey' strategy is primarily associated with the facts of some aspects of public life and is designed to investigate the relationship between cause and effect. Thus, it is influenced by the demographics, social environment, opinions, and attitudes of a group of people (Moser and Kalton, 1971, p.1). The main architecture of the survey is questionnaires or interviews or both which are posed to a population sample that are concerned with the research topic.

  It is impractical to send a questionnaire to a whole population that are concerned with the topic area, and hence, the sample size should be carefully selected to fully represent the whole population. The sample population should be unbiased and must be a true representation to reflect the overall opinion of the full population which further enables a generalisation of the findings (Bell, 2010).

  Schell (1992) argued that, a survey is one of the most suitable approaches of quantitative data *collection* that focuses on contemporary records and events. The survey approach possesses special qualities that makes it the leading approach to construct reliable indices and data validation that were collected from the field observations (Sieber, 1973).

Although, surveys are widely adopted by researchers and university students, it is often challenged with the few responses that negatively affect generalisation of the research findings. Takim *et al.*, (2004) reported that the normal survey response rate is usually 20-30% of the overall tested sample.

- **Archival Research:** the term 'archival' is linked with historical data; however, it may also refer to contemporary records (Bryman, 1989). Essentially this type of research refers to using available recorded data in many different forms such as minutes of meetings, documents such as specifications, day-to-day records, financial records, and any form of previously collected data (Runeson and Höst, 2008). There are two forms of archival research classified based on the source of data, i.e. the main and secondary (Saunders *et al.,* 2009).
  The main archival research data refers to the contemporary or research data that is collected from reliable sources such as government entities (Bryman, 1989). Whilst, secondary data includes paper and/or paperless correspondences such as emails, minutes of meetings, progress reports etc.

  Archival research has been challenged due to missing data, which is sometimes deemed crucial, mainly because, the archived data is developed as part of daily tasks and not specifically for the research purpose (Runeson and Höst, 2008). For that reason, Flynn *et al.,* (1990) have recommended combining archival research approach with other data collection approaches such as survey to acquire or compensate for the missing data.

- **Case study**: although there is no standard definition for the 'case study,' approach it is commonly referred to the strategy for conducting research that involves empirical investigation of a particular contemporary phenomenon within its real-life context using multiple sources of evidences (Robson, 1993, p. 146). It is usually adopted to extensively investigate a phenomenon which is usually not clear from the outset of the research (Benbasat *et al.,* 1987). According to Roethlisberge (1977) the case study research strategy is appropriate particularly for certain types of problems, particularly, those in which the research and theory are at their early formative stages. In the same context, Yin (2008, p.9) affirmed that, the case study is suitable for exploratory research, that includes with daily operational activities that need continuous tracing over time, rather than casual events.

The fundamental difference between the case study and other research strategies, is that in the case study, the researcher has prior knowledge of what the variables of interest will be and how it will be measured (Benbasat *et al.,* 1987, p. 370). Runeson and Höst (2009, p. 132) established that, the case study is well suited for many kinds of engineering research.

According to Robson (2002) the successful strategy for a case study should include, but not limited to, the following elements:

- ***Objectives***: what to achieve?
- ***The case***: what is to be studied?
- ***Theory***: frame of reference.
- ***Methods***: how to collect data?

Although, the case study is one of the most widely adopted approaches, it is challenged by Barzelay (1993) who considered generalising findings from a single case study as unreliable, specifically for social science, mainly because the case study cannot replicate the population.

However, the findings of a case study concerning engineering science, information system and commonly shared problems are usually reliable, and can be effectively generalised (Robson, 2002, p.166).

- **Ethnography:** this is the study of people in their naturally settings/fields, where data tends to be collected by capturing people's social meaning, cultural behaviour and normal activities over a prolonged period (Brewer, 2000, p.6).

The researcher usually immerses their self with the people under the study to understand the situation from the inside and experience people's views (Robinson, 2007; Bradford and Cullen, 2013).

Ethnography employs many methods and techniques for data collection such as participant observations, interviews, interaction analysis, studying historical records and the use of demographic data (Lutz, 1986; Bell, 2010). Klein and Myers (1999) and Easterbrook *et al.,* (2008) considered ethnography as a special type of case study that focuses on the cultural behaviours for numerous participants over a prolonged tenure.

Technically, ethnographic study classified as qualitative approach that has special distinguishing features over other research strategies, wherein ethnography uses a close-up approach to enable the researcher themselves to collect detailed observations from the field of the study. Moreover, the researcher starts the study without any commitment or bias towards any theory or conceptual model (Stake, 1983; Lincoln and Guba, 1986; Jacob, 1989). The findings lead to developing theories rather than testing them (Bell, 2010, p.88).

Ethnography is challenged due to its generalisation of its findings and as the study conducted in only one field which often differs from other fields. Moreover, integrating the researcher into the field study is a challenging task which is often not feasible due to the prolonged duration required to conduct the ethnographic study that may be extended to several months or even years (Vesa and Vaara, 2014). Therefore, ethnography is not a suitable research strategy for post graduate research students, mainly because they have a limited time to finish their research and often, they cannot devote themselves to the ethnography case study.

- **Action research**: this is the study of a social situation which involves the participants to act as researchers with a view to improving the quality of action with it (Rapoport, 1970; Elliott, 1980). It is the research strategy used when an existing practice needs to be improved with the addition of a new development (Cohen and Manion, 1994a).

  In action research the professionals or participants, need to study their own practices to improve it. According to Denscombe (2007, p. 123) action research involves feedback loop in which the initial findings generate possibilities for change which are then implemented and evaluated as a prelude for further investigation.

  Guffond and Leconte (1995) defined five essential processes for the action research which includes *problem formation, action hypothesis, implementation, interpretation and diagnostic cycle*.

  Critiques of action research claim that it is recognised as a complex research strategy, as it requires the researcher to work from inside the study, moreover, there is no control over the research duration due to the required continuous improvement cycles (Bell, 2010).

- **Narrative inquiries:** This is a qualitative research strategy, whereby, the researcher interviews one or more individuals who voice their experiences about their social life (Riessman, 2008). The researcher asks to follow up questions which gives the storyteller the chance to clarify and substantiate the collected data about their personal experience (Gray, 1998). The researcher then transcribes their stories and rearranges them; *chronologically* and subsequently, the researcher analyses the data after adding their perspective therefore creating a collaborative narrative (Creswell, 2009; Clandinin and Connelly, 2000).

According to Bell (2010) this research strategy is a problematic approach, particularly when conducting it for the first time. Moreover, the analysed information tends to embody misunderstandings, missing information and chronological gaps. Narrative inquiries are suitable only for social research that studies traditions, customs, cultural and historical behaviours for the people (Flick, 2006).

- **Grounded theory**: This is a qualitative strategy sought to develop theory that is grounded in empirical data collection and analysis, with the researcher starting the research without any specific theory in mind. However, the theory evolves during actual research as a result of continuous analysis of the collected data (Strauss and Corbin, 1967). The main premise of the grounded theory is not testing the hypothesis but developing a new theory that emerges from the empirical field data collection.

  Accordingly, the developed theory transcends from theoretical concepts as it emerges from 'real life' rather than theoretical concepts. Moreover, grounded theory embraces distinctive features that distinguish it from other research strategies such as continuous comparative analysis, data collection and analysis transpiring simultaneously rather than in a linear sequence (Dunne, 2011). Moreover, Payne (2007) highlighted the dynamic interplay between data collection and the analysis is a unique feature in the grounded theory strategy.

  Grounded theory is unlike other research strategies, whereby, in typical strategies, the researcher needs to develop knowledge about the research problem identified from the literature study. However, grounded theory implies that, the developed knowledge should be augmented and verified by the empirical field data collection.

  Atkinson *et al*., (2007) considered grounded theory a widely adopted strategic approach, especially for post graduate students who are researching construction, engineering, information systems, management or undertaking scientific research.

4.6.1 The adopted research strategy:

The assumed pragmatic research philosophy has led to an adoption of a mixed strategy that combines qualitative and quantitative dimensions to enable an appropriate response to the research problem and objectives.

The nature of the research and its objectives compelled the adoption of grounded theory at the outset of the research. The inductive qualitative approach of grounded theory enables development of the theory from an interactive real-life perspective, such as interviews with professionals who have practical experience in construction projects combined with robust in-depth knowledge of delays in construction. Interviews with professional participants from the construction industry are expected to add and enrich the research from the practical experience.

Moreover, what makes the grounded theory is the right selection, is that, it fits perfectly with the standard processes of the design science for proposing a novel solution that stems from the practical experience.

Commonly, grounded theory has significant harmony with the case study approach, mainly because grounded theory paves the way for testing the effectiveness of the proposed solution as a real-life case study (Patton, 2002).

Finally, validation of the proposed system/solution via online survey allows a comprehensive comparison of the effectiveness of the proposed system, in comparison to conventional monitoring and notification approaches.

According to Zelkowitz and Wallace (1998), conducting surveys following a case study will give exacting information about the tested solution.

Obviously, grounded theory followed by case study and online survey sit perfectly with the processes of design science for developing a novel solution to solve a research problem (Vaishnavi *et al.,* 2004; Hevner *et al.,* 2004).

4.7 Time horizon

Time horizon is the time over which the research is conducted from the beginning until concluding the findings (Saunders *et al*., 2009). The research objectives and questions are the main drivers to define the selection of the time horizon (Robson, 2002; Saunders and Tosey, 2011). According to Saunders *et al.,* (2009) the answers for the following questions determine which time horizon will be the most appropriate:

1. Do I want my research to be a "*snapshot*" that focuses on specific time? or,

2. Do I want my research to be more akin to a *"series of snapshots"* and a representation of events over a given period?

If the researcher's answer is "yes" to the first question, accordingly, the cross-sectional time horizon is the right choice. According to Robson (2002) and Easterby-Smith *et al*., (2008) cross-sectional usually employs survey or case study.

However, if the answer to the second question is "yes," that means the longitudinal time horizon is the correct choice, which usually involves experiments, ethnography, grounded theory, action research and narrative inquiries.

4.7.1 The adopted time horizon:

The research seeks to test and validate the proposed system within a case study determined by a limited duration. Based on the above, the study is a snapshot; therefore, cross-sectional time horizon is the best choice.

4.8 Techniques and procedures:

It is important to select the correct technique and procedures, primarily as the research findings are inevitably affected by the adopted techniques and procedures (Saunders *et al*., 2009).
Determining the technique through which data will be collected needs to complement the research philosophy, strategy, and the time horizon. Data collection does not have to encompass just one technique; it is quite possible for a questionnaire and case study or interviews alongside a questionnaire to be used, or whichever combinations the researcher sees necessary for the research (Naoum, 2013).
There is a wide range of data collection techniques such as interviews, questionnaires, observations, questionnaire, Delphi survey and focus group.

The following section suggests different data collection techniques and procedures.
Interviews: Interviews are considered as a purposeful discussion between two or more people (Kahn and Cannell, 1957). According to White (2000, p.29) an interview is a popular form of data collection that can provide, when properly conducted, a rich source of material. Within the realm of research, interviews help the researcher to collect reliable and valid data that is pertinent to the research objectives or enable the formulation of the research objectives.

Indeed, the real benefit of interviews is that it puts the researcher face-to-face with the interviewee(s), so both parties are clear about the question(s) and the answers and any ambiguity can be clarified instantaneously (White, 2000; Bell, 2010).

According to Fellows and Liu (2008) there are three main types of interviews (1) structured interview, (2) semi-structured interview and (3) unstructured interview as discussed below:

1. **Structured interview**: in this technique the questions are presented in the same order using the same wording to all the interviewees, which gives the researcher full control of the interview (Naoum, 2013). This technique tends to develop a response pattern reflecting the views of interviewees for the research problem and accordingly, the researcher needs to record the responses from each interviewee independently for further analysis (Saunders *et al*., 2009).
   Robson (2002) claimed that, the structured interview technique is convenient if the research objectives are predefined.

2. **Unstructured interview**: this is an in-depth interview which often referred to as a qualitative exploratory research interview (King, 2004). It has no pre-prepared questionnaire list; yet, the researcher should be clear about the research topic that is going to be explored (Saunders *et al*., 2009). The researcher and participants interact freely without any predetermined norms such as structured questions (Naoum, 2013). Saunders *et al.,* (2009) argued that, structured interview approach relies mainly on interactive discussion and the talent of the researcher to derive the information from the interviewee.
   This technique is appropriate where researcher is seeking information to develop the research objectives; the researcher will start the interviews without the research objectives being formulated.

3. **Semi-structured interview**: This type of interview will usually use a combination of closed and open-ended questions to explore solutions from the participants' insights (Tashakkori and Teddlie, 1998). It gives more freedom to the interviewer than the structured interview, whereby, the researcher starts the interview with a pre-prepared questionnaire. However, the researcher has the freedom to change the questions and its order to explore and aggregate more insights from the participants (Naoum, 2013). Additionally, King (2004) mentioned that, a semi-structured interview is a non-standardised interview which often referred to as qualitative research interview.

Saunders *et al*., (2009) claimed the semi-structured interview is suitable for a group interview, where the researcher often meets the interviewees face-to-face to explore solutions to the research problem. According to Robson (2002) and Saunders *et al*., (2009) it is the most suitable technique for exploratory study that seeks to understand the relationships between the variables.

Obviously, semi-structured interview perfectly fits with this research study. Mainly because at its first stage construction industry professionals will be asked open-ended questions to evaluate the features and components of the proposed system, derived from the analysis of state-of-the-art systems in the development of approaches, tools and techniques in the detection and notification of project overrun. As the second stage involves evaluation and verification of the effectiveness of the developed prototype from the pilot project case study, from the users of the prototype via open-ended questions.

Observations: This is the action of recording events and phenomenon that the researcher listens to or watches (Fellow and Liu, 2008). It is commonly utilised for qualitative research, particularly where the research topic involves studying interactions of humans, animals etc (Flick, 2006). However, observation is also applied in quantitative research specifically laboratory experiments, whereas, the researcher uses all or some of their senses (listening, watching, smelling, touching, and tasting) to record any changes (Bell, 2010).

The observation research technique has received significant criticism such as, it is time consuming (Saunders *et al.,* 2009), there is a tendency for researchers' bias (Bell, 2010), the validity and reliability of the collected data are subject to the researcher's skills in observing and interpreting their observations (Flick, 2006).

Questionnaire: It is one of the most widely adopted techniques amongst researchers for data collection (Naoum, 2013) and consists of a series of questions in a systematic and ordered fashion (White, 2000). This technique is used largely for descriptive or explanatory research (Saunders *et al.,* 2009). Exploratory research tends to employ open-ended questions to collect subjective data pertaining to human cultural study, organisational behaviour or to seek the opinions and practical experience of the participants (Flick, 2006). Conversely, explanatory research often employs close-ended questions to collect objective data which enables examining and explaining relationships between the variables i.e. cause and effect (Saunders *et al.,* 2009).

The researcher's decision "*which type of questionnaire will be adopted*" is influenced by the research objectives, the respondents, sample size, and the number of questions in the questionnaire (Naoum, 2006; Saunders *et al*., 2009).
In this context, Bell (2000) has categorised the questionnaire into two main types, the postal questionnaire and self-administrated questionnaire.

- **Postal questionnaire:** is the questionnaire that "*sent and received through the email*"; it is one of the most popular techniques for data collection. This type of questionnaire is cheap and fast; however, the researcher has no control on the number of responses, and as such there tends to be a low rate of return. Therefore, the researcher should send the questionnaire to many participants and consider that the shorter and clearer the questionnaire is, will relay in a greater number of responses (White, 2000).
  One of the key criticisms of the postal questionnaire is that, the researcher cannot guarantee whether the respondents well comprehend the questions (Fellows and Liu 2008). Therefore, Naoum (2006) recommended testing the questionnaire in a pilot trial to check the clarity and comprehension of the questionnaire and the ease and time required in competing the questionnaire. This gives the researcher the opportunity to amend the questionnaire accordingly before sending out to a large population.

- **Interview-administrated questionnaire:** this involves direct interaction with the respondents where, the researcher asks questions and receives the answers instantly which are the recorded and transcribed (White, 2000). This type of questionnaire can be conducted face-to-face, or by using Skype or telephone, and the like (Suanders *et al*., 2009).

  The advantage of the interview-administrated questionnaire is that the researcher has full control of the questionnaire and can ensure all questions are answered, with the interviewee having a clear understanding of all the questions, and wherein any ambiguities are clarified by the researcher (Naoum, 2006; Suanders *et al*., 2009). Accordingly, the collected data is considered reliable (Robson, 2002).

  However, interview-administrated questionnaire can be challenging as it can be difficult to arrange time to go through this type of questionnaire with senior or executive managers due to their busy schedules (Naoum, 2006; Suanders *et al*., 2009).

Delphi survey: The Delphi survey is a type of quantitative data collection seeking to elicit consensus, by engaging several rounds of questionnaires with the participants concerning the research topic (Young and Jamieson, 2001).

The design of Delphi survey is built on undertaking a number of rounds, where participants are requested to complete the questionnaire individually without sharing or discussing their responses with others and participants are usually unknown to each other. At the end of each round the researcher collects and statistically analyses the survey responses and shares the results with the participants anonymously. Responses are usually shared to show the agreements and disagreements in a form of average, mean, and standard deviation (Hasson *et al.,* 2000).

The process of the second round is a replica of the first one, however, the feedback solicits the participants to reassess their responses of their earlier questionnaire. Iteration is processed until approximate consensus is achieved (Ludwig, 1994; Hsu and Sandford, 2007; Fellows and Liu, 2008).
According to Custer *et al.,* (1999), three iterations are often enough to achieve the consensus that qualifies collection of reliable data.

The Delphi survey is challenged as a time-consuming technique, Ulschak (1983) and Ludwig (1994) recommended that, the minimum duration required for conducting Delphi technique is 45 days. Additionally, it is criticised for its low rate of responses, due to the repetition, whereby, some participants discontinue in the subsequent rounds (Witkin and Altschuld, 1995; Hsu and Sandford, 2007).

The basic premise of the Delphi survey is to achieve consensus or approximate consensus that implies equivalent knowledge of the participants of the research problem, even if they are from different backgrounds (Altschuld and Thomas, 1991). However, this assumption is not often true (Marchant, 1988; Altschuld and Thomas, 1991), and accordingly, the outputs of the Delphi technique pertaining to high technology, Information Systems and IT are not reliable (Hsu and Sandford, 2007).

Indeed, this research study seeks to develop an automated system based on high technology (software and hardware). However, the reported unreliability of Delphi technique correlated with the high technology led to not adopting Delphi as the technique for data collection for this research study.

Focus group: Several researchers have criticised individual interviews as they are costly and time consuming, additionally, the discretion of participants can sometimes result in unclear or superficial views (Flick, 2006; Bell, 2010; Masadeh, 2012). Accordingly, grouping the participants within a focused interview environment can enable discussion which is seen as a resolution to these issues that arise from interviews (Pollock, 1955; Fellows and Liu, 2008; Naoum, 2013).

The literature study revealed there are many definitions for focus group-based discussion. Morgan (1997) defined a focus group as "*an established rigorous technique for collective interviews aimed at eliciting and exploring in-depth opinions, judgments and evaluations expressed by professionals, experts or users/clients about specific topic*".

A definition provided by Marczak and Sewell (2007) and is deemed more comprehensive, as "*a group of interacting individuals having some common interest or characteristics, brought together by a moderator, who uses the group and its interaction as a way to gain information about a specific or focused issue".*

Lately, the focus group has become one of the most adopted exploratory qualitative research approaches (Kim *et al.,* 2005; Masadeh, 2012), mainly because it involves a group of experienced, practitioners and experts who usually have robust in-depth knowledge about the research problem (Morgan, 1988; Bell, 2000; Saunders *et al.,* 2009).

According to Flick (2006) the aim of the focus group discussion is to analyse the common processes of problem solving. Therefore, the researcher should introduce the research problem in a clear manner with the participants interacting with each other in an open and dynamic discussion willing to listen to others' views. Accordingly, the group's task is to discover alternatives through the discussion and then, propose and justify the best solution (Billson, 1989; Saunders *et al.,* 2009). The involvement of the researcher in the focus group is limited to a role as a mediator or organiser rather than interviewer (Bell, 2010). Accordingly, selecting the correct participants of the focus group is crucial to involve specialists that cover all the research disciplines to allow investigation of the research problem from all aspects.

Billson (1989) and Barrows (2000) asserted that the adoption of a focus group prior to starting a quantitative approach tends to act as a heuristic manoeuvre that delves deeper into the research topic to assist the researcher in developing a profound understanding of the research problem. Practically, focus groups are an efficient way of gaining a large amount of information (Barrows, 2000; Masadeh, 2012). Billson (1989) claimed that, the output from a focus group usually results in the proposed development of a new artefact or inventive solution.

A focus group involves a questionnaire, which could be structured, semi-structured or unstructured, however, several researchers criticised the structured questionnaire as it confines and leads the discussion among the participants, which deprives them from expressing their insights openly (Flick, 2006; Bell, 2010). Accordingly, the more flexible the discussion of the focus group, the more profound the data collection.

Flick (2006) highlighted that a focus group is suitable for the researcher who has less information and wants to investigate, explore or aggregate more data about the research problem and in particular, that is related to empirical and practical experience. In the same context, Krueger (2002) established that a focus group plays a pivotal role for improving the plan and design for new programs and systems.

Procedures for successful focus group:

Flick (2006) has set certain criterions for conducting a successful and smooth focus group; the first step for a successful focus group is that the researcher should introduce the participants to each other and welcome them. And then, they must introduce the research topic and the problem statement.

It is fundamental to ensure interactive discussion amongst the participants at all times, and to that end, the researcher usually starts with an open stimulus question as an icebreaker that increases the likelihood of all participants sharing their insights and experiences (Herkommer, 1979; Flick, 2006).

Obviously, the researcher cannot note down the participants' answers while moderating the discussion, thus, video or audio recording for the discussion is strongly recommended after obtaining the necessary permissions from the participants. However, in case the consent is not obtained for audio or video recording an assistant will be required to minute the discussion (Flick, 2006).

Several researchers consider focus groups, a cost-effective data collection technique which can be conducted as face-to-face or remotely via a median of communication such as Skype (Dreachslin, 1999; Wall, 2001; Krueger, 2002; Kosny, 2003) and the number of questions limited to an absolute maximum of ten to avoid the participants being distracted and a prolonged meeting (Billson, 1989).

However, the number of the participants in a focus group is a controversial issue which has been widely debated. Young (2003) stated that the ideal number of participants in a focus group should be four whilst, Morgan (1988) and Ruyter (1996) claimed it should be five, Prince and Davies (2001) stated six participants seem to be more effective, and Marczak and Sewell (2007) stated seven, and Leitão and Vergueiro (2000) and Evmorfopoulou (2007) stated eight. Likewise, Leitão and Vergueiro (2000) and Evmorfopoulou (2007) considered the most effective number of participants in a focus group is between six and eight. Prince and Davies (2001) claimed that between five and six participants is the most commonly used sample size for focus group discussion in the UK and several other countries.

Evidently, there is little consensus on the sample size for focus groups and is therefore left to the researcher's discretion based on their evaluations and needs (Evmorfopoulou, 2007). Fiske and Kendall (1990, p. 137) specified two guiding rules based on which the focus group size should be determined. It should not be so large that it results in precluding participation of any of the members but likewise, should it be so small that it fails to provide enough depth that could equally be covered in an interview with an individual participant.

Even after considering the maximum number of participants in a focus group, Gibbs (1997) and Daniels (1999) considered that sample size too small to be able to generalise the findings. Therefore, it is recommended not to use a focus group merely for data collection; however, it should be used in conjunction with other approaches such as a case study, interviews or survey (Billson, 1989; Morgan, 1997; Flick, 2006, Fellows and Liu, 2008).

Characteristics of focus group discussion: According to Krueger (2002) there are four elements of the focus group discussion as follows:

- **Participants:** It is recommended to carefully identify relevant participants who can add value to the discussion.
- **Environment:** It was also recommended that the environment, where the focus group discussion is undertaken, should be comfortable with a rounded table, so as to enable the participants to see each other, or in the case of a Skype meeting to agree on a convenient time for participants.
- **Moderator:** if the researcher will act as the moderator for the focus group discussion, they must have the ability to embrace the following skills, otherwise, an external moderator must be recruited.
    - A. Exercise mild unobtrusive control
    - B. Have an adequate knowledge of topic
    - C. Have the discipline to lister
    - D. Able to create a warm and friendly environment
    - E. Control the dominant members of the group
    - F. Involve quieter participants
- **Analysis and Reporting:** The researcher must carefully listen several times to the recorded discussion of participants alongside any notes taken during the discussion to find the big ideas.

A Focus group within construction research: Although, the focus group was devoted initially for humanities, social science and marketing research, lately, it had grabbed the attention of construction management researchers' as an effective qualitative technique sought to collect in-depth data (Ereiba *et al.,* 2004, Flick, 2006).

The following Table 4.1 illustrates comparisons between the focus group technique and other data collection approaches showing the superiority of the focus group as a data collection approach specifically in construction research. Table 4.1 was developed by Ereiba *et al.,* (2004) based on Langford and McDonagh (2003) research.

Table 4.1: Comparison review between focus group technique and other techniques used in construction research

Technique	Description	Benefits	Limitations
Focus Group discussion	Discursive interaction between participants (e.g. a sample of users), guided by a facilitator (moderator/researcher) focusing upon particular issues	-Focused data, revealing experiences and reasons for behaviour, can be elicited in a short period of time; -Help researchers to become immersed in the user's ' world of thought' and terminology; -Flexible technique -Provide good data for exploratory research type	-Relatively high cost (e.g. recruitment administration, participant fees, data analysis); - Qualitative data from conversations are difficult to formalise or use as statistically secure evidence
Questionnaires (Forms)	Retrieving feedback through use of forms with pre-determined questions (e.g. using prepared feedback boxes, rating scales and opportunities for comments	-Feedback is short and precise as comments are restricted; -Tick boxes can be analysed statistically	-Limited level of detail and flexibility of responses; - Statistical analysis may be unsuitable due to small sample sizes; -People often prefer talking to writing
Individual Interviews	Researcher and interviewee discussing a certain topic (could be structured, semi-structured or unstructured)	-Reveals experience of the interviewee in-depth	-Qualitative data from conversations are difficult to formalise or use as statistically secure evidence -Difficult to generalise
Workshops	Discursive interaction between participants in an educative manner, where participants change their experiences and views about a certain topic	-Participants are actively involved and produce a tangible output	It is not considered an appropriate research method for researchers collecting new information

Source: Ereiba et al., (2004), used with permission from Tony Thorpe

Advantage of focus group technique in construction research

Several researchers have cited the advantages of the focus group technique as an effective data collection method and the following table depicts these advantages in terms of enabling a profound understanding, richness of the collected data, reliability, tendency to propose innovative solutions, less formal and laborious, the collection of a large amount of data in short time and a low cost technique.

Table 4. 2: Advantage of focus group technique in construction research

Profound understanding	A Focus group assists the researcher in developing practical knowledge of the research topic, especially for increasing knowledge from the literature study or adding empirical and practical understanding to the academic knowledge (Morgan, 1997).
Richness of the collected data	The data collected collectively in an open discussion from various disciplines tend to cover the research topic from all aspects (Gibbs, 1997). Accordingly, this in-depth knowledge assists the researcher to develop novel and innovative solutions to the research problem (Saunders *et al.,* 2009).
Data reliability	The collected data is reliable, mainly because it emerges from the practical experience gained by experts and practitioners (Bell, 2010).
Finding/proposing solutions	The participants of the focus group are experts and practitioners, and as such, their insights tend to assist the researcher to find solutions or propose new models that did not exist before (Litosseliti, 2003).
Less intimidation and laboriousness	The collective discussion of the focus groups makes it less intimidating than individual interviews and less daunting than questionnaires, which make it suitable technique for data collection at the outset of the research study (Ereiba *et al.,* 2004).
Large data in a short time	It is an effective technique for data collection in a short time period through gathering all interviewees in a dynamic discussion which usually takes place over 1-2 hours (McClelland, 1994; Threlfall, 1999).
Low cost technique	Unless there is a need to recruit a mediator, book a venue, and pay for the participants, it is a very low-cost technique (Dreachslin, 1999; Leitão and Vergueiro, 2000; Wall, 2001).

4.9 The overall research design outlining the adopted technique and procedure

Research design is about communicating the method the researcher wants to employ to accomplish the research objectives by deciding the methodological approach in finding solutions to the research problem, with much consideration given in defining the research philosophy and methodology (Fellows and Liu, 2008, p.83). According to White (2000, p.25) the research design is an overall plan of the research that includes selection of the appropriate methodology, the data collection technique, the chosen methods of data analysis and how all these fits in with the literature.

The research design is the logic that links the data to be collected and the conclusions to be drawn (Yin, 2008). This research study adopted a pragmatic philosophy and an exploratory sequential mixed method (qualitative and then quantitative approach) which enabled exploration of breadth of the research problem to propose a practical solution for the identified problem.

This research study followed the design science standard processes to ensure the correct implementation and efficiency of the research; design science processes were considered as a well-defined, organised and consistent with a pre-prepared checklist that is compatible with the nature of this study.

The ultimate deliverable of this research study is proposing a new automated system that seeks to instantly detect and notify delays in construction projects. This research adopted the pragmatic strategy, which entails execution of this study in three stages as illustrated in the below Figure 4.2.

4.9.1 Stage 1-Pre-development stage (objective1)

- **Literature Review**: Extensive investigation to acquire deeper knowledge of existing literature to understand state-of-the-art systems for current monitoring and updating systems with a special focus on limitations, advantages and the technology employed for each initiative. The *output* of the literature review is a "*conceptual framework*" for the proposed system.
- **Focus group (qualitative approach):** the focus group will be conducted with seven carefully selected professionals who have practical experience of construction projects combined with robust in-depth knowledge of delays in construction. To select the participants of the focus group a simple online survey (Appendix 2) will be sent to construction professionals via LinkedIn in addition to the researcher's own network of contacts.

The seven selected participants will all be asked open-ended questions (Appendix 4) to evaluate the conceptual framework that was derived from the analysis of state-of-the-art systems in the development of approaches, tools and techniques for the detection of project overrun. Participants' answers were analysed using NVivo software. Ereiba *et al*., (2004) established that the focus group provides an in-depth understanding of the research problem which adds strength to the research, especially from those pertaining to construction management.

The *output* of the focus group is "*comprehensive knowledge of what to develop*" as the most suitable automated system proposed to detect and deal with delays in construction projects.

4.9.2 Stage 2- Development, testing, verification and validation of the effectiveness of the system

As shown in Figure 4.2 this stage divided into two substages, the first sub-stage (stage 2-I) involves development of the prototype and the second sub-stage (Stage 2-II) involves validation of the final version of the developed system as elucidated hereunder.

4.9.2.1 Stage 2-I: Development, evaluation and verification of the system's prototype (Pilot project case study via qualitative approach- objectives 2 and 3)

This stage involves proof of the concept, developing, testing and verification of the proposed automated system to detect delays and timely automated notifications to support decision-makers. Participants of this stage will be 9 users of the system representing the contractor, consultant and owner. They will be asked open-ended questions (questionnaire is found in Appendix 4) via face-to-face interviews, to evaluate and verify the effectiveness of the developed prototype. The prototype will be continuously developed and improved according to the users' comments and feedback until it accomplishes full satisfaction.

The *output* will be a "*prototype that is tested, evaluated and verified by a representative sample of construction professionals, and ultimately, to developing the final version of the system that meet users' satisfactions*".

4.9.2.2 Stage 2-II- validation of the final version of the proposed system (case study- quantitative approach- Objective 4)

This stage aims to validate the proposed system, which will be utilised in a construction project from its onset to allow comprehensive comparison of the developed system against conventional monitoring and updating approaches. The online survey in Appendix 10 will use Qualtrics and will be administrated and sent to the system's end-users to assess the effectiveness of the final version of the system. The collected data from 40 end-users (i.e. contractor, sub-contractor, consultant, and owner) will be analysed using SPSS. Deliberately, the users in stage 2-I are not the same in stage 2-II, to allow the aggregation of various and additional views about the system. Fowler (2008) and Creswell (2009, p.43) established that, the survey provides a quantitative or numeric description of trends, experience, or opinions for the collected data with the intention to generalise the findings. The findings of the survey tend to be rigorous and reliable (White, 2000).

The *output* of this stage will be a "*ready-to-use system developed for construction projects*".

4.9.3 Stage 3- Post-development (objective 5)

This stage will involve addressing the conclusion, limitations and further research studies of the proposed system.

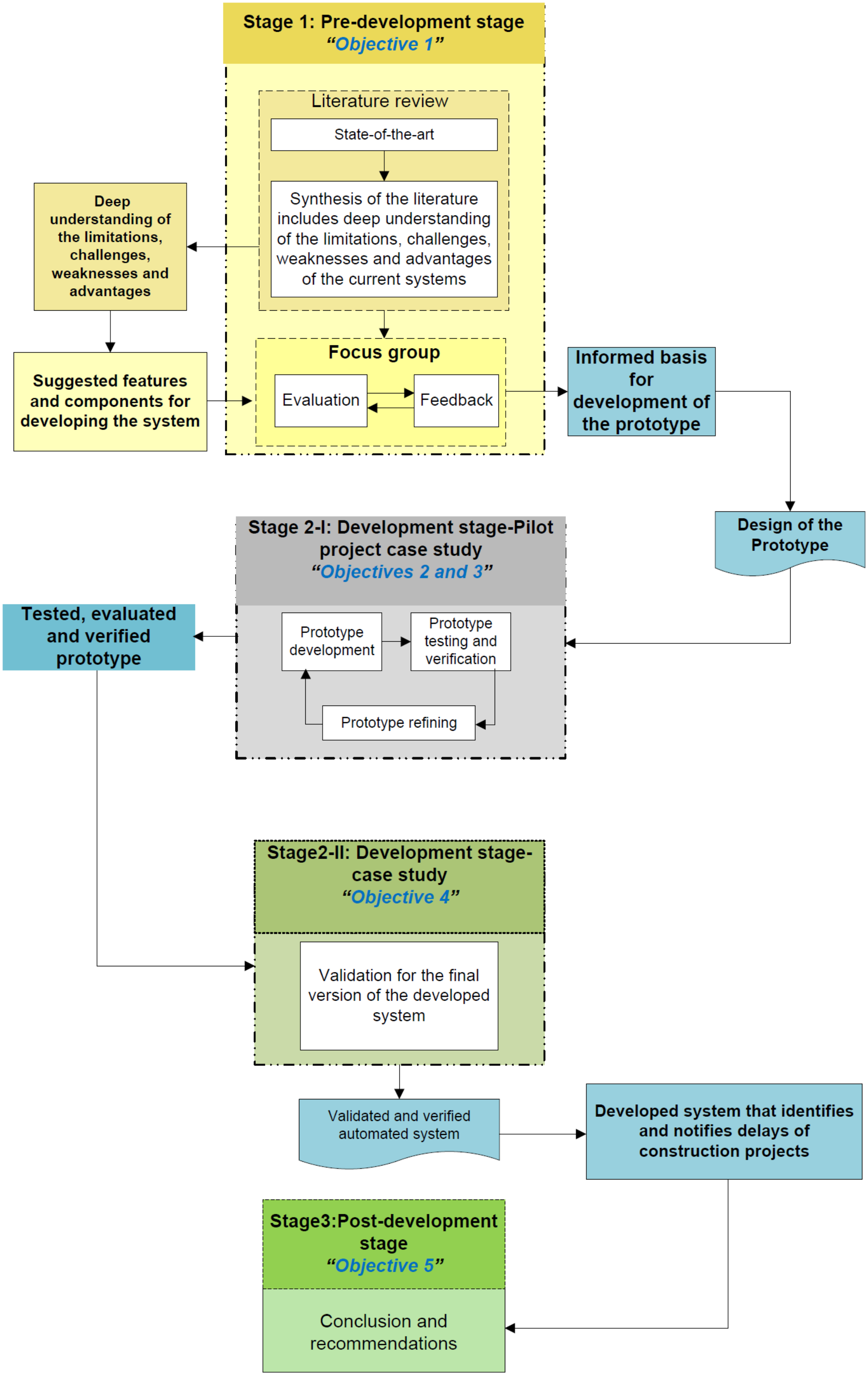


Figure 4.2: Overall research design outlining the adopted technique and procedure

4.10 Research ethics

Research ethics is one of the most important components of any research, particularly for post graduate research studies which often involves a large number of participants (White, 2000). According to Flick (2006, p. 36) research ethics is the formulated code to regulate the relationships between the researchers and the people and fields they intend to study. Principles of research ethics entails the researcher to avoid harming himself as well as the participants involved in the study by respecting and considering their needs and interests. This research study is designed and conducted with full compliance of the stipulated ethical requirements for post graduate research at The University of the West of England (UWE). Moreover, to ensure full compliance ethical approval was obtained from the Faculty's Research Ethics Committee (FREC) prior to collecting any data.

In this regard, the researcher has introduced a brief about the study and its characteristics as PhD research. Moreover, the participants rights were reviewed with them, with enlightenment on the strict confidentiality of their data which is solely used for research purposes, in addition to, emphasising their right to discontinue their participation at any time during the research. Data was collected anonymously whereby participant names and responses were not shared. Consent forms and the ethical information sheet are attached in Appendix 1.

4.11 Chapter summary

Success of any research study is intrinsically linked with selection of the suitable research design and methodological approaches for data collection and analysis. The below Table 4.3 summarises the adopted research design, where, the research objectives and problem formed the basis for selecting the design science research processes.

1. A simple ***postal online survey*** was sent to construction industry professional groups in Dubai via LinkedIn in addition to the researcher's network to enable the selection of the seven participants in the focus group (***quantitative approach***).
2. ***Face-to-face interviews*** were conducted via ***focus group*** discussions, conducted to collect the data from the carefully selected industry professionals (***qualitative approach***).
3. After developing and testing the prototype by nine users in the pilot project ***case study***, they were ***interviewed in a face-to-face*** approach to collect the data for measuring evaluation of the effectiveness of the proposed system (***qualitative approach***).

4. After further refinement of the prototype, the final version of the system was developed, tested and evaluated in a full lifecycle ***case study***, with data collected from the 40 users via ***online survey*** for the final version to evaluate and validate the system (***quantitative approach***).
5. Finally, the conclusion and recommendations are articulated based on the data analysis and findings.

Table 4.3: The overall research design

	Stages of the research study		
Research design	**Pre-development**	**Development**	**Post development**
Research philosophy	Pragmatic		Conclusion and recommendation of the research
Research process	Design science		
Methodological choice	Mixed method - Exploratory		
	1. Quantitative 2. Qualitative	1. Qualitative 2. Quantitative	
Research strategy	Grounded theory		
Time horizon	Cross sectional		
Techniques	Focus group	1.Pilot project case study. 2. Full-life cycle case study	
Procedures for data collection	1. Structured 2. Semi-structured interview	1. Face-to-face interviews, interrogation via semi-structured questionnaire. 2.Online Survey administered for data collection via postal questionnaire.	

Chapter 5- Qualitative inquiry: Data collection at the Pre-development stage

5.0 Introduction

The aim of this chapter is to establish an informed basis for the development of the automated system. Accordingly, it provides a full overview of all the stages in the development of the proposed system, starting from the pre-development stage following onto the two substages of the developing stage to the final development of the system that is ready to be rolled-out into construction projects. And finally, the post-development stage.

The trigger for developing the proposed system commenced at the pre-development stage with the collection of data by means of the focus group discussion, and consequently, the purpose of and procedures for conducting the focus group were established. Furthermore, selection of participants and the sample size were introduced and justified, and finally the adopted approach to analyse the collected data qualitatively was chosen and justified.

5.1 Outlines and stages for conducting the research study

This research seeks to develop an automated system to detect and notify of delays once occurred to assist decision makers in making timely decisions to recover incurred delays in the construction projects. To that end and in line with the design science processes this research study was executed in three main stages as follows.

- Pre-development stage (chapters 5 and 6)
- Development stage (chapters 7 and 8)
- Post-development stage (chapter 9)

These stages for developing the proposed system adopted the same approach to what (Thomas-Alvarez and Mahdjoubi, 2013) adopted in their research. Whereby, they initially employed a focus group to determine the effect of the conceptual prototype of their portal from the recipients' cognitive responses (*the pre-development stage*). Afterwards, based on the findings of the focus group, they developed the web-portal (*the first stage of the development stage*) which was initially tested and evaluated to gauge its effectiveness. Following, the portal was fully developed and enrolled for testing, and the users of the portal were requested to respond to an online survey which was administrated to validate the system (*the second stage of the development stage)*. Finally, the research conclusions and recommendation were addressed *(the post-development stage).*

5.2 Purpose of conducting the focus group discussion

Design science standard processes entail acquiring rigorous knowledge pertaining to ***awareness of the research problem***, which is the mainstay for successful implementation of the research. This stage involved an extensive literature review that was introduced in chapters 2 and 3 in addition to focus group discussion detailed hereinafter.

Subsequently, the second process of design science concerns "***suggestion***"; to propose a novel solution for the research problem. The researcher after a comprehensive study of the state-of-the-art systems proposed a tentative design for the prototype sought to detect delays and instantly notify decision makers with the project status.

The focus group discussion was conducted with selected professionals from the construction industry to *evaluate the features and components of the tentative design proposal of the system's prototype*. These features and components were derived from analysis of state-of-the-art systems in the development of approaches, tools and techniques in the detection and notification of project overrun.

Focus group discussion is a subjective approach that collects data from participants by a collective face-to-face discussion. According to White (2000) and Flick (2006) gathering experts and professionals from various disciplines together in a focus group discussion is the most effective approach for exploring practical solutions for a research problem. Masadeh (2012, p.64) asserted that, a focus group is an exploratory research method that has proved its efficiency in collecting data from a small number of people, who often provide useful and valuable insights about the research problem group interaction was well-organised.

According to Zikmund (2000) exploratory research is intrinsically linked with the need for a clear and precise statement of the research problem, which often leads to proposing innovative ideas that tend to contribute to resolving the research problem.

Accordingly, it is incumbent upon the researcher to precisely define the research problem, its attributes, selection of the right participants, and development of clear questions that allow a solution to be found for the research problem.

Several researchers have recommended various procedures for the successful completion of focus group discussion. However, there is a great deal of consensus amongst those researchers, in selecting of the right participants and drafting a clear agenda, including the questionnaire. The focus group agenda should outline specific criteria and guidance to be followed by the researcher as well as the participants to accomplish the required research objectives (Flick, 2006; Saunders *et al.,* 2009; Naoum, 2013).

5.3 Procedures of conducting the focus group discussion

There are several recommended approaches for administering a focus group; Flick (2006) recommended to defining clear criteria in the selection of the most fitting participants, that can add their in-depth knowledge to contribute in resolving the research problem. In terms of agenda, the research problem should be introduced, and questions posed to the participants to be discussed collectively. The researcher should record all answers to use their own judgment and analysis to seek the most appropriate solution for the research problem.

However, another approach as recommended by Krueger (2002) commenced with introducing the research problem and the state-of-the-art, then ask the participants to evaluate alternative solutions raised and developed from the literature study. Accordingly, participants discuss collectively how to justify their selection for the most appropriate option. However, in case that there is no consensus, the researcher should conduct additional focus group discussions with other participants to select the best solution.

This research adopted the second approach recommended by Kruger (2002), mainly because the research problem is well-defined, and the synthesis developed from the state-of-the art for similar systems as described in chapter 3. This in-depth knowledge offered conceptual solutions that needed evaluation by construction industry professionals via the focus group discussion. Moreover, introducing components and features of alternative solutions to the participants stimulated them to propose innovation solutions or to perfect the proposed solution (Kruger, 2002; Saunders *et al.,* 2009).

For successful implementation of focus group discussion, the following procedures were followed.

A. The research problem was well-defined and introduced in chapter 1.
B. Extensive investigation was carried out to acquire deeper knowledge of existing literature to understand state-of-the-art systems used for current monitoring and updating systems with a special focus on limitations, advantages and the technology employed for each initiative, which was conducted and introduced in chapters 2 and 3.
C. Clear criterions for selection of the participants are developed.
D. The agenda for the focus group is prepared.
E. Data collection and analysis methodologies are defined prior to starting the focus group discussion.

5.3.1 Selection of the participants

The participants for this research were carefully selected to provide a sample that represents various construction industry disciplines (i.e. contractors, consultants, clients, software developer, BIM manager).

This research did not approach or involve any participant that may not be able to understand verbal explanations or written information in English. The research adopted a *purposive sampling technique* that is referred to as a judgmental or expert sample, a type of non-probability sampling, in which the researcher depends on his own judgment when selecting a representative sample to participate in the study.

Saunders *et al*., (2009, p.239) recommended the *purposive sampling* approach to select participants of a focus group to acquire in-depth knowledge which is often used to pave the way for alternative approaches such as a case study to achieve the research objectives.

Therefore, purposive sampling was selected, mainly because this research sought to gauge the judgement of experienced construction professionals about the fitness for purpose, effectiveness and robustness of the proposed concept to detect delays and provide timely notifications. Consequently, it requires participants with a grounded knowledge and expertise in construction projects, including dealing with delays in construction.

Accordingly, the focus group was conducted with carefully selected professionals who have practical experience in construction projects combined with robust in-depth knowledge of delays in construction. Furthermore, the participants' behaviours were thoroughly checked to avoid dominant talkers, those too shy to participate in open discussions and those who are difficult to control.

All participants of this research were selected from construction professionals in Dubai, mainly because, the researcher works as a specialist (head of technical development unit for Dubai Electricity and Water Authority) for the government of Dubai. Another key reason for involving participants from Dubai is that the pilot project and the full life cycle case study that involves developing, testing, verifying and validating the proposed prototype and the final version of the system was conducted in Dubai.

The participants of the focus group were made up of seven construction professionals with on average fifteen years of practical experience within construction projects combined with robust in-depth knowledge of delays in construction, as a prerequisite condition for selection of participants.

A sample of seven participants was deemed appropriate, mainly because it allows for quality time for each participant to freely express their in-depth knowledge. Krueger (2002) and Kosny (2003) recommended five to seven participants as the ideal number for focus group discussion to allow enough time for each one to eloquently express their particular point of view. Moreover, the seven selected participants represented all the required expertise and discipline varieties i.e. two contractors, one consultant, two owners, one BIM manager and one software programmer concerned with developments in the construction industry.

Indeed, several authors have proposed software systems based-BIM as the solution for the research problem (El-Omari and Moselhi, 2011; Ibrahim *et al.,* 2009; Golparvar-Fard *et al.,* 2009; Golparvar-Fard *et al.,* 2011; Dimitrov and Golparvar-Fard, 2014; Behnam *et al.,* 2016). Accordingly, a software programmer and BIM manager were involved in the focus group discussion. Another key reason for limiting the sample size to seven participants, is to avoid prolonged discussion and enable better control of the discussion.

To recruit the most suitable and qualified participants that work from different perspectives, a simple online survey questionnaire consisting of six questions (Appendix 10) that required in average 5 minutes to answer was sent to construction industry professionals in Dubai. The online 5 minute survey was chosen for the initial stage to select participants for the focus group, due to its ease in deployment, and its use via a free online survey platform such as Qualtrics saving time and money. The recruitment process sought to promote the survey by using LinkedIn groups to share the URL link for the online questionnaire within construction industry groups in Dubai. The promotion of the questionnaire on LinkedIn, contained all the necessary information, such as proposed length of time, the aim of the questionnaire, and request to read the information sheet and consent form.

Participants who agreed to participate in the focus group interview were requested to confirm they had read and understood the participant information sheet and sign the consent form and to reply with their contact details such as email and mobile number.

In addition to professional construction groups on LinkedIn, participants were selected from the researcher’s own network as well. LinkedIn groups included “Dubai construction networking” (1,219 members), The "Construction Project Leads" Network - # 1 Group for Construction Professionals” (42,285 members), “Construction network-UAE” (1,217 members).

Hence the sample size was determined in two steps as follows:

1. Determining the sample size for population by using the following formula developed by (Cochran 1977).

Necessary Sample Size $$\mathbf{SS} = \frac{(\mathbf{Z\ score})^2 \times \mathbf{p}(\mathbf{1-p})}{\mathbf{m}^2} \quad \text{......... Equation 1}$$

Where:

Z score: 1.96 the most common confidence levels (1.96)

p: population proportion (assumed to be 50%=0.5)

m: margin of error (generally taken as 10%)

$$\text{Necessary Sample Size }(S) = \frac{(1.96)^2 \times 0.5(1-0.5)}{0.1^2}$$

Necessary Sample Size (SS) =96.04

2. Adjust the sample size to the required population. The participants of the focus group should have experience of delays in construction industry; hence the expected number of populations is assumed as 2000.

$$\textbf{Adjusted sample size} = \frac{S}{1+\frac{S-1}{population}} \text{.... Equation 2}$$

$$\textbf{Adjusted sample size} = \frac{96.04}{1+\frac{96.04-1}{2000}} = \mathbf{91.68}$$

Adjusted sample size=**92**

This result suggests that **92** responses are required to provide a valid sample size to select the seven participants from, for the focus group. This number appears realistic as it will be carefully refined to exclude those who were qualified but did not have the enough time to participate.

5.3.1.1 Responses of the online survey

Although, the link of the simple online survey was shared and sent to more than 45,000 professionals via the above-mentioned LinkedIn groups, in addition to the researcher's network; only 211 responses were received, of which only 113 respondents met the stipulated criteria for selecting the focus group participants.

From the 113 respondents, participants who are dominant talkers, lacking in confidence to participate in open discussions and difficult to be control were excluded. These personal behaviours and traits were assessed and judged after an initial individual face-to-face interview prior to starting the focus group discussion. Ultimately, only 13 participants were left, that matched the prerequisite conditions for the focus group. Out of the 13 participants seven were selected as the main group and the rest provided a backup group, in case any of the participants were unable to attend the focus group discussion, or a second round of discussion was required, the backup group would be involved.

The 7 participants who met the above mentioned criterions were officially invited via email to which the invitation letter and information sheet were attached (Appendix 3).

The following Table 5. **1** demonstrates the biography of the seven participants who were involved in the focus group discussion. Table 5. **1** illustrated the average experience for the participants as 19 years and their average work experience in Dubai as 12 years.

Table 5. 1: Participants of focus group discussion

Participant code	**Specialty**	**Designation**	**Experience (Years)**	**Dubai experience (Years)**
MK	Contractor	Director	28	21
EK	Contractor	Project manager	22	14
AS	Consultant	Project manager	23	16
AH	Owner	Projects manager	19	12
VK	Owner	Senior engineer	13	8
JK	Freelancer	BIM manager	12	6
GE	Freelancer	Software programmer	14	7
Average			**19**	**12**

5.3.2 Agenda of the Focus group discussion

In order to explore the research problem, the focus group discussion employed open-ended questions to allow the participants to express their experiences and insights freely and openly within an environment of interactive discussion.

The agenda defined the researcher and participants' responsibilities, the rules to be followed during the discussion, the venue, duration for the discussion, and the questionnaire. The agenda was sent two weeks prior to the date set to allow enough time for the participants to reconsider their interest and to confirm their participation. Fortunately, all the initial seven selected participants confirmed their presence, interest and willingness to participate.

To ensure clarity throughout the discussion, participants were invited to ask questions at any point to clarify any ambiguity that may arise, and they were also asked to use full terms instead of abbreviations or jargon. Moreover, to assure collection of all the required data and optimum control on the focus group, open-ended questions were prepared as attached in (Appendix 4) and used as guidance for ensuring full coverage of the research problem from all aspects.

The questionnaire was designed to investigate "*causes of delays in construction industry", "the most appropriate approach based-technology for monitoring and controlling delays in construction projects", "the best feature, and technology for data collection from construction sites" , "the suitable methodology for reducing or removing the occlusion for the collected data", "the most suitable time for capturing data from the site", "the most suitable media of communicating the updates", and "the time for sending the updates to the decision-makers".*

5.3.3 Conducting the focus group

According to Masadeh (2012, p.66) the moderator plays a pivotal role in determining the success of the focus group, and to this end, the researcher must select someone with personality traits considered to be the cornerstone of successful moderation.
However, Nassar-McMillian and Borders (2002) recommended, the researcher should act as moderator if they found themselves capable of moderating and controlling the discussion, mainly because the researcher is the most knowledgeable about the research problem.

Accordingly, this research did not recruit a moderator as the researcher considered himself qualified enough to act as moderator, primarily as the researcher had moderated several discussion panels at conferences and chaired approximately 500 meetings for the last thirteen years within his capacity of project manager and head of the technical development unit. Furthermore, the researcher has in-depth knowledge of current and emerging technologies concerning the control and detection of delays in the construction projects.

According to Krueger (2002, p. 4) the first few moments in the focus group discussion are critical, and therefore, it is incumbent on the moderator to create a thoughtful, permissive atmosphere, provide ground rules, and set the tone of the discussion. Additionally, the success of the focus group discussion is anchored to the development of an open discussion environment.

To enable to have smooth focus group discussions, several researchers such as Evmorfopoulou (1998), Krueger (2002), Ereiba *et al.,* (2004) and (Flick 2006) have recommended that focus group should follow the following four processes:

i. **Welcome**: the moderator should start the discussion session with a welcome message, in which participants are thanked for accepting the invitation. It is important for the researcher to introduce himself and then introduce the participants to each other.

Fortunately, five out of the seven participants already knew each other. According to Kosny (2003, p. 542), the focus group that consisted of people already knew each other or had several commonalities was richer than those involving participants who did not know each other or had no commonalities.

ii. **Overview of the topic**: the researcher had incorporated a ten minute presentation outlining the research problem, state-of-the art for the proposed solution based on the literature review and what is expected from the participants in addition to the agenda and ground rules for the basis of discussion.

iii. **Opening question**: the opening question is essential breaking the ice, and to encourage the participants to share their thoughts; it is deemed a stimulus question. The first few moments within a focus group discussion are critical, thus, the opening question should be plain and easy to answer to encourage participants to share their thoughts (Krueger 2002). To that end, the first question was simple and general, but, related to the research problem. The opening question was "*How do you see the performance* of *the construction industry in terms of delays*?"

iv. **Ground rules**: the researcher/moderator stressed certain principles such as there are no wrong answers but rather differing viewpoints and urged the participants to feel free to share their thoughts and to ask to talk if the question is not addressed directly to them. Moreover, participants have been encouraged to share their insights even if it is opposed by others, as ultimately, as professionals there is no offenses if one's viewpoint is opposed.

Additionally, the researcher reminded the participants about the pre-agreed duration, which was 3 hours; the session started at 9:30 AM. However, the session was extended with full consent from the participants and finished at 2:15 PM with a 25 minute break. The session lasted for four hours and twenty minutes, which allowed for 36 minutes for each participant to talk which translated into an average of 6 minutes for each participant per question.

The researcher confirmed anonymity for all the participants with commitment that, the findings will be used only for this research study. Accordingly, a verbal consent was obtained from the participants to record the discussion.

It is worth mentioning, the researcher was flexible in that the pre-set questionnaire was not strictly adhered to. However, the re-order and addition and omission of questions was done pursuant to the discussion flow and emerging themes. As such, Appendix 4 shows the final questionnaire that was posed to the participants.

5.4 Analysis of qualitative data - focus group discussion

The carefully selected seven participants in the focus group were requested to share their thoughts and insights. The researcher asked the participants open-ended questions to evaluate the features and components of the proposed system that derived from the analysis of state-of-the-art systems in the development of approaches, tools and techniques in the detection and notification of project overrun.

According to Mihas (2019) qualitative data analysis is the process of analysing textual, visual, or audio data. Dey (1993, p.31) defined qualitative data analysis as the process of putting data into its constituent components, to reveal its characteristic elements and structure. It is also known as the process of developing theory from the collected data (Saunders *et al.,* 2009).

According to Saunders *et al.,* (2009) qualitative data follows one of two reasoning approaches, the deductive approach and inductive approach. The *Deductive approach* is suitable for research that has already developed theoretical propositions prior to collecting the data (Yin, 2003). However, this approach is challenged on the principle that it develops the theory and proposition prior to data collection and is at risk of introducing a premature closure on the issues to be investigated. It is also argued that the analysis tends to repudiate the participants' insights. Additionally, the researcher's judgment is highly influenced by the prebuilt theory during data analysis which may end up with findings that starkly contrast with reality (Saunders *et al.,* 2009, p.489).

The second approach is the *inductive approach* which starts with data collection to be used initially for exploratory purposes to assist in constructing the theory or the conclusion. In other terms, the inductive approach means the research starts with the data collection and is followed by data analysis to determine the conclusion, which means the research moves from the particular stance, to generalise the research experience (Corbin and Strauss, 2008; Yin, 2003); this approach is also referred to as the *grounded theory* approach (Saunders *et al.,* 2009).

In fact, the literature study found a wide range of approaches used for the analysis of qualitative data, such as ***interpretive analysis***[1], ***narrative analysis***[2], ***content analysis***[3] and ***grounded theory analysis***[4] (Kawulich, 2004; Flick, 2006; Fellow and Liu, 2008; Naoum, 2013).

Bernard (2000, p.439) argued that, in ***interpretive analysis***[1], the researcher continually interprets the words of the transcript data to understand their meaning and derivative. According to Denzin (1989) ***interpretive analysis***[1] is suitable for biographical research that involves personal tensions and public policies.

The second qualitative analysis approach as claimed by Coffey and Atkinson (1996) is ***narrative analysis***[2] which concerns the participant's experience as narrated in a historical sequence, indicating the occurrence of events. Thus, this approach is suitable only for the historical and narrative research (Flick, 2006).

Hsieh and Shannon (2005, p. 1278) defined ***content analysis***[3] as "a research method for the subjective interpretation of the content of text data through the systematic classification process to identify patterns". According to Downe-Wamboldt (1992, p. 314) the main goal of ***content analysis*** is "to provide knowledge and understanding of the phenomenon under study". Therefore, Flick (2006, p.328) recommended ***content analysis***[3] is the most suitable approach to facilitate the comparison of different ontological facts to which it is applied throughout.

The following approach is the fourth qualitative data analysis approach which is selected for this research, reasons for selection are justified hereinafter.

5.4.1 Grounded theory analysis[4]

Grounded theory was introduced in chapter 4, section 4.5 and the rational for selecting this approach was introduced in section 4.5.1; the output of the grounded theory analysis offers analytical findings rather than descriptive, the ultimate goal is the development of a conclusion to the research problem (Hood, 2007, p.154).

Saunders *et al*., (2009) concluded that, in the grounded theory approach, the theory emerges from the constructive interaction between the researcher and participants which results in the integration of in-depth knowledge that enables data collection and analysis. This approach also requires the predevelopment of a clear research problem alongside an aim and objectives to steer the selection of the type and method of data collection. Furthermore, this approach allows the researcher to identify the relationships between the collected data and the developed objectives. All the above rationales in addition to section 4.5.1 support the selection of the *grounded theory analysis* as the qualitative data analysis approach at the outset of this research.

According to Flick (2006) the research must undergo through the following steps to analyse data according to the grounded theory analysis schema:

A. **Transcription of data:**

The focus group discussion was recorded, and notes were taken during the discussion. Afterwards, the researcher listened several times to the recorded discussion and carefully converted the recorded audio into textual script. Davidson and Silvana (2011) defined transcription as the interpretation and translation process of audio and/or video records into scripted text that can be further studied and coded.

B. **Organisation of the data**:

The researcher further organised the transcripts to reduce its quantum by creating an intercorrelation, which accordingly, assisted the derivation of themes for the collected data, and then linking the themes to the research objectives which makes it easy to refer and infer information. Miles and Huberman (1994) emphasised that, systematic arrangements that correlate the discussion adding answers to the research objectives are immensely helping to validate data analysis.

C. **Categorising concepts and coding data:**

According Nübold *et al.,* (2017, p. 6) coding is a procedure through which researchers create meaningful labels for sections of text. Basically, coding is to support making sense of the data (Rich, 2012). Iterative reading of the transcript assists the researcher in establishing and marking specific words and expressions that were used by the participants to categorise ideas and concepts for recognising the emerging themes.

According to Vaismoradi and Snelgrove (2019) categorising concepts is the process of developing taxonomy, by identifying the relationships between and similarities of the participants' answers. Moreover, categorisation is the first analytical process for the scripted data which assists the researcher to develop codes (Flick, 2006).

Approaches for developing codes from the text.

There are two main approaches for developing codes from texts; the *first approach* involves a manual procedure which is tedious, laborious, cumbersome, and time consuming, in which researchers use a *coding dictionary* to facilitate the coding procedure. The *Coding dictionary* is defined as a document that assists and guides the researcher in categorising the text according to continual comparative analysis of existing codes (Kreiner *et al.,* 2009; Nübold *et al.,* 2017).

The *second approach* employs software such as NVivo to help the researcher derive codes and assists in finding themes within few minutes. NVivo is a computer aided software program developed specifically to assist researchers to analyse qualitative data, by feeding the textual scripts of the discussion into the software which results in finding codes and themes of the data automatically (Alharbey and Chatterjee, 2019).

Moreover, employing NVivo to analyse the collected data improves accuracy, saves time and allows the researcher to find in-depth analysis by changing some attributes which would require several hours work using the manual analysis approach (Strauss and Corbin, 1998; Yearworth and White, 2013).

It is affirmed by Schmidt (2001) that the manual approach for analysing qualitative data from the focus group is complicated and time-consuming. Therefore NVivo 12 pro was selected to analyse the data from the focus group, to develop codes due to its accuracy and time savings.

D. Theory/conclusion emerges from developing themes:

Data analysis of the textual scripts from responses is initiated by developing categories of similarities and contrasts; this development of categories facilitates the coding of the data which accordingly allows a development of themes. Javadi and Zarea (2016) defined themes as the outcome of coding transcripts from textual data. Therefore, development of themes requires utmost attention as it is the process which leads to the emergence of the theory and conclusion. Braun and Clarke (2006) described themes as the final product of qualitative data analysis for the focus group discussion. According to Erlingsson and Brysiewicz (2017) and Vaismoradi and Snelgrove (2019) a theme is the red thread of underlying meanings, within which similar pieces of data can be tied together and within which the researcher may answer the question of "why?".

Accordingly, this analytical process develops themes which requires the researcher’s judgment to prioritise them and often to interlink them and further check them against the research objectives. According to Vaismoradi and Snelgrove (2019) the researcher must use their own judgment in the development of themes to evaluate their ability to develop valuable and innovative knowledge that assists the researcher to develop an innovative solution that emerges from a practical grounded experience.

To that end, the developed themes were thoroughly reviewed for abstracting the overarching theme of the discussion. The codes and themes are discussed hereunder.

5.5 Data collection from the focus group

Participants of the focus group were introduced to different approaches of site data collection such as satellite, close-range photogrammetry and laser scanning, of which they were asked to determine the most appropriate approach to detect delays.

They also were exposed to different features and components of the proposed system, methods to opt the suitable that enhances the effectiveness of the proposed system. They were also requested to select the most effective media for communicating notifications of detected delays, whether through the browser, emails or SMS.
They were further requested to choose, which duration of sending notifications was more effective; daily, weekly or any other regular duration. And finally, the criterions for assessing the effectiveness of the proposed system were developed based on the contribution of the participants in the focus group discussion. The focus group discussion was recorded, and notes were taken. As the discussion was progressing, codes and themes were emerging and becoming unequivocal to the researcher. Screening and iterative reviews for the script allowed a certain level of prediction of the codes, even before the acquisition of them from NVivo software. The following section introduces data analysis using NVivo software.

5.6 Chapter summary

This chapter outlined the stages for development of the proposed system which starts with the focus group, and accordingly, the focus group discussion with seven carefully selected construction professionals with an in-depth knowledge of construction site activities and project overrun was conducted. This chapter also introduced the purpose and procedures followed for steering the focus group. Ultimately, the steps for analysing the collected data were introduced, in addition to the justifications of employing NVivo software as a data analysis tool. The following chapter introduces the data analysis, results, findings and discussion of the focus group.

Chapter 6-Data Analysis, Results, Finding and Discussion for qualitative data enquiry at the Pre-development stage

6.0 Introduction

The purpose of this chapter is to analyse and present the findings of the focus group discussion at the pre-development stage, and to subsequently enable development of the prototype for the proposed system. Accordingly, this chapter introduces the data analysis of the collected data using NVivo and further discusses the findings which determined the features and contents of the proposed system.

Moreover, the successful criteria used for measuring the effectiveness of the proposed system were suggested by the participants of the focus group. Finally, the last section introduces the steps of the theoretical development of the proposed system.

6.1 Framework for developing the proposed system

The Pre-development phase is the stage wherein the system is not physically developed. This phase involved extensive study of the literature to gain in-depth knowledge of the current and emerging endeavours to instantly detect and notify the delays in construction projects. As a result, the comprehensive literature review assisted the researcher to conceptualise a promising prototype which required further discussion with construction industry professionals. Focus group discussion was conducted with professionals who were asked to contribute their insight in selecting the most suitable features and components to develop the long-overdue system to assist decision makers to complete their construction projects without cost and time overrun. The following section outlines the features and requirements of the prototype that were discussed in the focus group interview.

6.1.1 Features and components of the proposed system

Developing the automated system required comprehensive understanding of the main functionality of the system and the way that the site teams interact and their expectations from the system. The literature review outlined the main features and components of the proposed system as follows:

The layout of the technical and operational requirements for the proposed system

- The system should instantly detect and report the delays.
- The system should display the delays in a "3D viewer" for ease of understanding.
- The "3D viewer" should display the delays in percentage terms as well as bar charts.
- The system should automatically send daily or weekly emails or SMS' to the decision makers notifying them with the occurred delays.
- Technology such as AI, photogrammetry and BIM should be employed for developing the fully automated system, and accordingly, human intervention and subjectivity are avoided.
- The system should be accessible at anytime from anywhere.
- The outputs of the system should be accurate and reliable.

General requirements

- The system should not impose any additional obligations or costs on the project.
- The cost of the system should be affordable to all construction project size including small projects.

In addition to discussing the above-mentioned features and components within the focus group, criteria for measuring the effectiveness of the developed system were discussed and results and findings are reported hereunder.

6.2 Focus group results and findings

The word mapping shown in Figure 6.1 illustrates the results from the analysis of NVivo 12 pro, which assisted the researcher to be more confident about the developed codes and accordingly in envisioning the proposed solution of the research problem. The developed codes were: ***close-range photogrammetry, notifications via emails and SMS, data capture two times per day, daily notifications, updates early morning and automated system.***

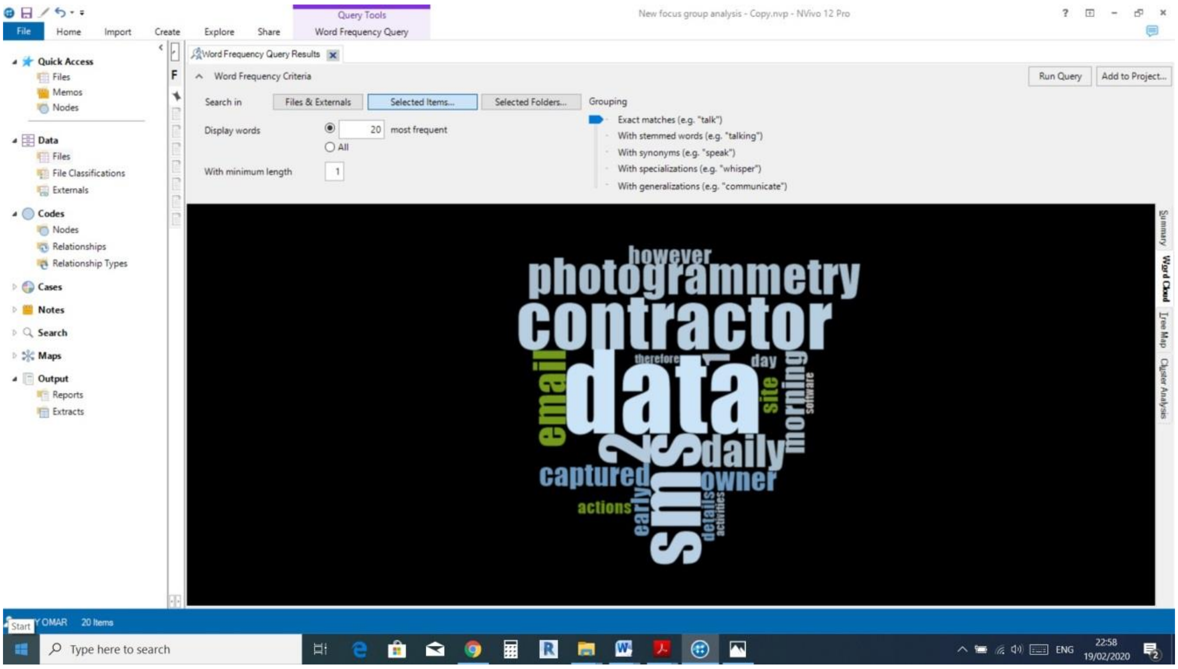


Figure 6.1: Screen shot for NVivo word map illustrates keywords for codes

Based on the aforementioned codes, themes were organised as shown in Table 6.1 below:

Table 6.1: themes developed from the focus group discussion

Theme	Sample of participants quotes (not all quotes are included)	Remarks
An ***Innovative solution*** is crucially required to notify the site staff of any delays	• It is clear that there has been no significant advancements made in project management strategies and no distinctive use of technology. Technology reverberates around us but we do not have the resolve to adopt new technologies, possibly due to preventative costs or uncertainty and sometimes, because it disturbs our familiar working practices (MK). • In my 22 years' experience I did not finish a project by its contract completion date (EK).	According to the discussion, delays in construction warrant prompt action to improve construction industry performance.
The architecture of the proposed solution (the proposed prototype)	• A photogrammetry system that uses one of the available software such as ContextCapture, Recap, Agisoft or Pix4D will enable the building of a 3D point cloud model to represent the as-built status. The 4D BIM model will enable recognition of the as-planned activities; and	The theoretical framework for developing the prototype is well devised.

	algorithms should be developed to enable comparison between both models, which will significantly contribute to finding the discrepancies between as-built and as-planned. • Occlusions are inevitable and therefore, should be reduced by capturing photos at times when there are the minimum amount of movement for both machines and labour; and therefore, photos should be captured before the site opens at 6:00 AM or after the site shuts down at 4:00 PM. • There is no consensual agreement for the question "How frequently should the system send the automatic updates, whether daily, weekly or fortnightly. • Some participants justified daily updates so they can evaluate any necessary actions required on either a daily or weekly basis. However, other participants suggested that for longer-term projects with a duration of 2-3 years, weekly updates are more appropriate as the impact of a one or even five day delays do not cause significant delay in the whole project. And therefore, any actions could be taken on a weekly basis. • Updates should be sent via SMS and email early morning i.e. 7:00 AM. • Users should be granted access to the system from any location, that would be based at the site (VK).	

The following section discusses the findings of the focus group.

6.3 Discussion of the proposed prototype

The constructive discussion in the focus group proposed several features that assisted the researcher to develop the prototype theoretically. The participants of the focus group agreed and emphasised all the above found in Table 6.1 and discussed the layout of the technical and operational requirements for the proposed system. This was in addition to the general requirements mentioned in section 6.1.2. The following sections introduce the main discussion points of the focus group.

6.3.1 The need of an automated system for detecting and notifying the delays in construction projects

All participants have postulated that most problems in the construction industry are as a direct or indirect result of time delays. Accordingly, managing and controlling delays will result in enormous improvements for the construction industry.

A great deal of consensus was reached amongst the participants, that the current monitoring systems are either cumbersome, prone to errors, inaccurate, require specialists to operate, and are often unreliable. Notably, much of these systems are expensive which make them prohibitive for a wide range of projects, and in particular small and medium size projects. Moreover, to date, the current systems lack the ability to notify and update decision makers with the delays instantaneously as occurred.

These findings correspond with Turkan *et al.,* (2012) and Omar *et al.,* (2018) who highlighted that, current monitoring systems are often unreliable, time-consuming, costly, and prone to subjectivity and errors.

[EK] stated that an innovative solution is crucial to enable instant detection of the delays once occurred.

[VK] affirmed there have been numerous attempts to propose an innovative solution based on the latest technologies for detecting the delays in construction projects such as those introduced by Ibrahim *et al.,* 2009; Gloparvar-Fard *et al*., 2009; Roh *et al.,* 2011; El-Omari and Moselhi, 2011; Dimitrov and Gloparvar-Fard, 2014; Braun and Borrmann, 2019. However, these systems failed to assist decision makers in preventing delays within the construction industry, and accordingly, a revolutionary solution is critically required to enable instant detection of the delays once occurred.

In a response to the question "*who should take the charge for developing the system ?"*, [AH] stated that although almost all parties share responsibility for causing the delays from design stages until closing out the project; however, the contractor is the only party that can play a pivotal role in recovering the delays, mainly because delays materialise in the construction phase and the contractor is the only party that has full control of the project during this phase.

6.3.2 Features and contents of the proposed system

Much consensus was reached amongst the participants, who suggested exploiting the advantages of the previous attempts.

[JK] strongly supported the researcher's proposal built on employing BIM, to compare the as-planned schedule from the 4D model with the actual progress collected from site by HD cameras, to notify the project team through SMS and emails. Accordingly, the 3D viewer should be unobstructed as with the BIM 3D software to recognise the status of each construction element.

The researcher suggested installing HD cameras to capture photos, to which [EK] proposed installing these cameras on freestanding masts which should be connected wirelessly to avoid any disturbance during the performance of construction site activities.

The researcher proposed capturing photos which would then be processed to build 3D point cloud models using off-the-shelf software, and algorithms would then be developed to remove or reduce the occlusions that occur from movable objects. In this context, [JK] proposed reducing the occlusion starting at the point of capturing the site photos, by programming the cameras to capture photos, when movements at the site are at their minimum, for example at 5:00 PM (after the site shuts down) or at 6:00 AM (before work starts).

Based on the captured photos, a point cloud model will be developed with minimum occlusions, and further algorithms could be developed to clean the 3D point cloud model from occlusions. The cleaned 3D point cloud model will be compared automatically with the 4D BIM model using the Iterative Closest Point (ICP) algorithm to allow precise superimposition of both models. Algorithms would be then developed to compare the actual progress, which is represented by the point cloud, against the planned progress from the 4D BIM model for detecting the differences between the two models.

Indeed, this suggestion is an aggregation for the advantages and whilst evading the limitations that trouble current systems such as what was proposed by (El-Omari and Moselhi, 2008; Golparvar-Fard *et al.,* 2014; Braun and Borrmann, 2019).

Further to the discussion of when and how the notifications should be made, there was significant consensus amongst the participants to send the automatic notifications via SMS and emails, each day early morning. This is primarily due to whilst not everyone checking their email, however SMS is easy to see and access. Another key reason is that, sending notifications early in the morning allows the decision makers to take the necessary actions in allocating resources appropriate for that day.

Indeed, the constructive discussion with the professionals in the focus group resulted in adding new features to the proposed system, whereby, the novelty of the suggested system is latent in two main features as follows:

- The first is the ease of use and full automation of the proposed system which will be developed using AI and BIM and can be accessed anytime from anywhere.
- And the second is the instant notification via email and SMS, which was not found in any of the current systems proposed for automating progress updates in construction projects.

6.4 Criteria for measuring the effectiveness of the proposed system

Daghouri *et al.,* (2018) claimed that it is crucial to choose exact and appropriate measures for assessing the effectiveness of the proposed system. The extensive literature study revealed that, DeLone and McLean (1992) have produced the most widely adopted model for measuring the success of systems developed using software and hardware. They defined five measures to assess the effectiveness of the developed system, which are "*system quality, information quality, system usage, overall satisfaction and the impact of the system on the organisation"*.

These five measures were introduced and discussed with the participants of the focus group who added "*perceived usefulness of the system*, *low cost, and importance of the system*" to measure the effectiveness of the proposed system.

Nevertheless, there was considerable agreement from all the participants on the above-mentioned measures, however, they considered the paramount criteria to judge the success of the proposed system as follows:

1. The proposed system detects delays and sends timely automatic notifications to support decision-makers.
2. The proposed system accomplishes in making a substantial saving in terms of project time and cost due its ability in detecting and notifying of delays.
3. The outputs of the proposed system are reliable and accurate.
4. The proposed system is easy to use, fully automated and does not rely on human intervention.

6.5 Theoretical development of the prototype

Finally, the constructive discussion and further analysis, assisted the researcher to gain in-depth knowledge of "*an informed-basis of the development of an automated system*". This sought to develop an automated system for monitoring, controlling, and notifying the progress updates on a daily basis to support the decision makers in formulating appropriate responses to recover the occurred delays. Figure 6.2 illustrates the main concept of the fully automated and integrated prototype for monitoring and controlling construction site activities.

The proof of concept of the proposed prototype will be developed and verified in a pilot project case study, prior to rolling it out in a real-life case study for testing and validation.

The following section introduces the steps for developing the proposed system, in accordance with the standard processes of the design science.

- **Step 1: Site Analysis**

The theoretical proof of concept of the prototype will be tested and verified in a pilot project case study i.e. a construction project, thus the chosen site will be inspected to determine the appropriate number of and locations for the HD cameras. These positions will be enumerated to determine the appropriate method of camera calibration to enable the capture of clear and comprehensive detail for each image.

- **Step 2: Hardware Specifications**

Based on the site analysis from ***Step 1***, pertinent hardware specifications will be determined.

- **Step 3: Hardware acquisition and installation**

Hardware that fulfils the specifications determined in ***Step 2*** will be purchased and installed. HD cameras of a specific sensor size with an appropriate image quality output are the main constituent of the hardware. Installation of the cameras will be by means of freestanding masts or permanent attachment to existing structures. The installed hardware will be connected to a central unit via hardwire or wireless connectivity, which will be determined from the site conditions. The objective of the central server is to collect image stills from the installed HD Cameras.

- **Step 4: Data Acquisition**

At the project onset, 3D and 4D BIM models will be developed to the highest level of accuracy (process ‘6’ on Figure 6.2), and similarly, the base line construction schedule will be developed using Primavera P6 (process ‘8’ on Figure 6.2). Subsequently, the programmable HD cameras with high resolution will be installed to capture photos of the site at predefined times (process ‘1’). The 4D BIM model will be developed and detailed based on the base line construction schedule (process '6') which will be further used for comparisons with the point cloud model.

- **Step 5: Data Formatting**

Acquired data from the image stills will be sent automatically from the central server to a remote server where they can be appropriately formatted. Image stills will be automatically extracted from the files and data will be grouped together for photogrammetric processing.

- **Step 6: Data Processing**

Formatted data from ***step 5*** will be processed photogrammetrically to build a 3D point cloud model linked to the date and time range of the input data from the three capturing events (process '2'). The developed algorithms will clear any occlusions from the 3D point cloud model to make it suitable for the next process of data analysis (process '4').

- **Step 7: Data Analysis**

Resultant datasets from the repetition of ***steps 4*** through to ***6*** will be analysed and compared; by means of comparing the 3D point cloud model against 4D BIM model from preceding and succeeding datasets. This comparison will identify any discrepancies between the 4D BIM model (as-planned) and the 3D point cloud model (as-built) (process '7').

- **Step 8: Data Integration**

The resultant data from ***Step 7*** will be formatted and exported into project management software such as Primavera P6 (process '8'), where it will be used to measure project development and progress. The resultant integration will result in automatic notification updates via SMS and emails sent to project decision makers to keep them updated about delays and enable faster response times and better communication (process '9').

In the case of any discrepancies between the as-built and as-planned status', this will be reported to the site staff via emails and SMS (process '9').

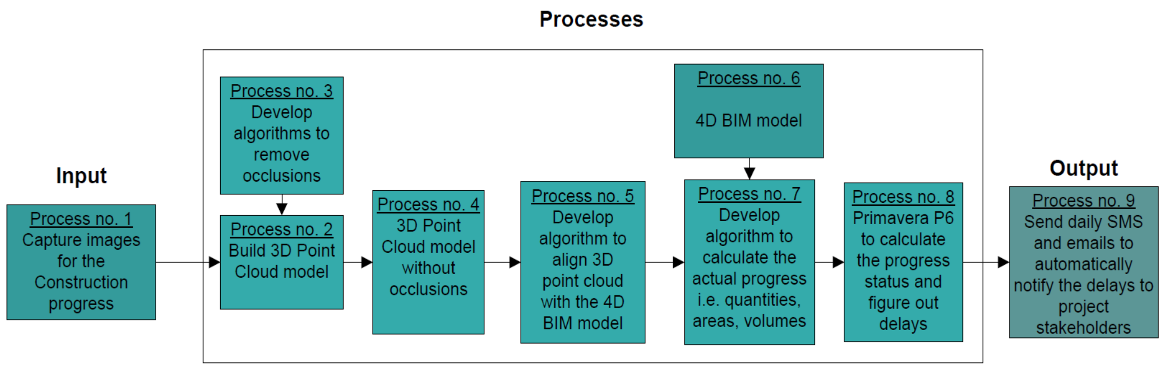


Figure 6.2: Theoretical development of the prototype for the proposed system

6.6 Summary for this chapter

The focus group assisted the researcher to acquire an informed basis for developing the prototype of the proposed automated system for detecting and notifying delays in construction projects. The prototype was designed to be operated using eight processes, which starts with data collection via image stills using HD cameras to build a 3D point cloud model which represents the as-built progress. The 3D point cloud model will be refined by applying the developed algorithms to clean the occlusions. Next the 3D point cloud model will be compared against the pre-prepared 4D BIM model to detect any discrepancies on a specified date. The detected discrepancies will be automatically exported to Primavera P6 to calculate the status for the project and for each deviated activity. The progress update will be reported and notified to the project decision makers via SMS and emails to support them in taking appropriate actions to recover the delays on a daily basis.

The prototype will be tested in a pilot project to verify the concept and will be then be validated in a construction project from its start date to end date which will be the real-life case study.

Chapter 7-Developing, testing and verification of the prototype-Development stage-I

7.0 Introduction

This chapter entails the development of a proof of the concept for the proposed automated system to detect delays in a timely manner and send automatic notification to support decision-makers.

Participants of this development stage include the management team (all the users of the prototype) representing a sample of contractors, consultants, and owners. They were asked open-ended questions via face-to-face interviews, to evaluate and verify the effectiveness of the developed prototype.

The collected data was analysed qualitatively using NVivo software to interpret the results into meaningful information and to obtain an in-depth appreciation of the users' experience in terms of what worked and what did not. This allowed the researched to identify the strengths and weaknesses of the system which could then be further developed. The prototype was continuously refined and improved in accordance with the users' comments and feedback, until the final version of the prototype was constructed resulting in a fully automated system.

7.1 Development stage- I: The pilot project case study

The proof of concept for the proposed system that sought to automate monitoring the construction progress was tested and evaluated in a pilot project case study. Bassi (2010, p.9) defined "*pilot project*" as the development and testing of a theoretical model on a small-scale level, in order to discover potential problems that otherwise would not be detected until full-scale deployment. Generally, the pilot project will be considered successful if the results realised the predefined criteria as proposed by the focus group; and accordingly, the tested model could be implemented in and rolled-out for larger scale projects.

Thus, this development stage involved converting the conceptualised prototype that was introduced in chapter 6 into an actual system that could be trialled in a pilot project; a real-life case study.

Testing the prototype in the pilot project allowed for flexibility when making a series of refinements, amendments, or revisions to the concept; eventually resulted in the development of a viable system that satisfied the research objectives. According to Herzog and Rolia (2001) it is important to ensure the performance of any system, that incorporates software and hardware, will meet its predefined successful measures before rolling-out the system in a full project. Unsatisfactory performance, when discovered late can cause adverse implications and costly redesign.

7.1.1 Developing, testing and verification of the prototype

In order to test the prototype appropriately in the pilot project, the development of the prototype followed the steps highlighted in chapter 6 section 6.5.

➢ **Step 1: Site selection and analysis**

Selection a site to develop and test the prototype was one of the fundamental factors of its success. According to Pardo-Del-Val and Fuentes (2003) proofing a new concept often does not attract attention nor support from most professionals. Moreover, any lack of support from the stakeholders tends to result in the proposed system being doomed to fail before it even starts.

To that end, the following criteria was predefined for appropriate selection of a pilot project that allows for a flexible, easy and smooth implementation of the prototype.

7.1.2 Criteria for selecting the pilot project

- The project should be in its early stages, especially for concrete elements.
- All drawings should be available as a 3D BIM model.
- Access to the site should be allowed at any time i.e. 24/7,
- Full permission to use the contractor's facilities such as internet, offices, and committed staff for assistance in installing the hardware including the HD cameras.
- The contractor should be cooperative and supportive to innovations, and ready to share information pertaining to the project.
- The ability to fixing hardware including the HD cameras without disturbing the ongoing construction daily operations.

Fifteen construction sites were visited, and only two sites were deemed suitable, meeting the above criteria. The selected pilot project case study was located in Dubai, mainly because the researcher works as a specialist (head of technical development unit) for Dubai Electricity and Water Authority (DEWA), the owner of the pilot project. Moreover, one of the key practical reasons for conducting this research in Dubai is primarily because the researcher is an overseas part-time PhD student, living and working in Dubai for more than 16 years. This long service in Dubai allowed the researcher to have a good network of professional working relationships within the construction industry in Dubai, as well as the authority to access to the real-life case study that facilitated data collection. Indeed, the research is conducted wherein the researcher is working; and accordingly, all participants of the pilot project case study are connected to the researcher as co-workers, stakeholders or peers. The following section introduces the details of the selected pilot project.

7.1.3 Description of the pilot project

The selected pilot project was 132/11Kv electrical substation owned by DEWA, in Dubai, United Arab Emirates with further details provided below:

Contract type: Design& Build (D&B)

Contract value: AED 70,998,750 ≈ (£ 14,790,000.00)

Description of the pilot project:

DEWA has one standard model for its 132/11 Kv substations, of which the dimensions of the main building of the substation are 60 metres x 50 metres with an inter distribution transformer and earthling transformer compound, fire pump room, underground services and boundary wall that follows the perimeter.

The work also included construction of all foundations, beams, columns, walls, together with the erection and installation of all electrical and mechanical equipment. The building consists of a *Basement, Ground Floor and First Floor*. The basement accommodates the High Voltage (HV) cables and major equipment such as 132 Switch Gear and 11kV Switch gear panels. The ground floor encompasses the control panels. Whilst the first floor houses the auxiliary cables. Figure 7. 1 and Figure 7.2 Shows a model of a standard DEWA 132/11 Kv substation.

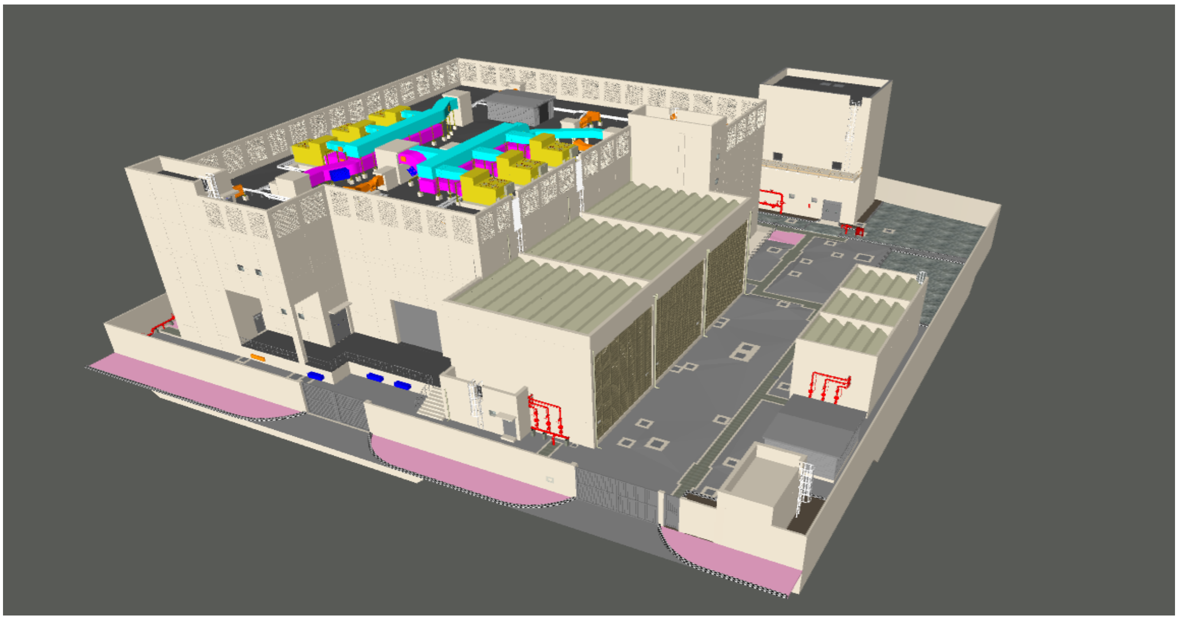


Figure 7. 1: 3D view of the 132/11 Kv substation (pilot project)

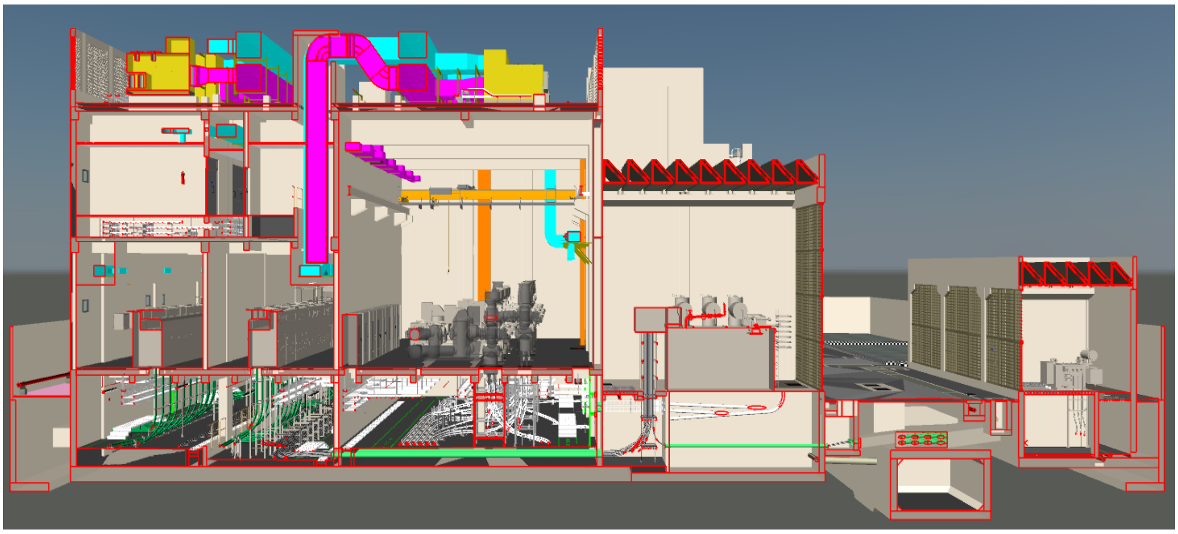


Figure 7.2: Cross sectional elevation for 132/11 Kv substation (pilot project)

According to the contractual conditions, the main contractor is responsible for updating the program of works to show the progress status and submit it to DEWA on a weekly basis as an integral part of the weekly progress report.

The selected site was analysed thoroughly to determine the suitable design of appropriate numbers and positions of the HD cameras, and accordingly, the hardware specifications are as follows.

- **Step 2: Hardware Specifications**

According to the analysis of the selected site, the following Table 7. 1 shows the appropriate hardware for this pilot project-case study.

Table 7. 1: The harware used in the pilot project

No.	Description	Unit	Quantity	Manufacture
A.) HARDWARE				
1	**Cameras:**	Nos	5	Hikvision
	❖ **Sensor:** 1" CMOS, effective pixels: 20M. ❖ **Lens:** FOV 84-degree 8.8 mm/24mm (35 mm format equivalent) f/2.8 - f/11 auto focus at 1 m - ∞. ❖ **Mechanical/electric Shutter Speed:** 8-1/2000 s; 8- 1/8000 s. ❖ **Shooting mode:** Auto+, Program AE, Shutter priority AE, Aperture priority AE. ❖ **Wireless File Transmitter:** Wireless File Transmitter WFT-E7 ❖ **Photo:** JPEG, DNG (RAW), JPEG + DNG ❖ **Operating Temperature:** Min/Max -10 °C/65 °C ❖ **Remote Controller/Switch:** Remote control with N3 type contact, Wireless Controller LC-5, Remote Controller RC-6 ❖ **Type: PTZ** ❖ **Outdoor camera**			
2	**Site WIFI Mesh: Ubiquiti Network Unifi UAP-AC-M - Wi-Fi extender**	Nos	5	UNIFI
	❖ **Working Environment**: Outdoor. ❖ **Speed**: Up to 2200 Mbps ❖ **WIFI Range**: Up to 1000 m^2.			
3	**Network Router:**	Nos	1	Cisco
	898G Cisco router C897VAG-LTE-GA-K9 (GE SFP VDSL2/ADSL2+ over POTS (non-US) 4G LTE / HSPA) + CON-SNT-C897VAGK9)			

4	**UPS:**	Nos	1	APC
	Smart-UPS 1500VA LCD RM 2U 230 V – Web based management – Email/SMS Down Time Notifications			
5	**Server 01:**	Nos	1	DELL
	Dell power edge R740 – 2xIntel Xeon Silver 4114 2.2G, 10C/20T, 9.6GT/s 2UPI, 14M Cache, Turbo, HT (85W) DDR4-2400 , PE 2U Standard Bezel ,64G 2x16GB RDIMM, 2666MT/s, iDRAC9,Enterprise , 1x 800G SSD 2x300GB 15K RPM SAS 12Gbps 512n 2.5in Hot-plug Hard Drive, 3.5in HYB CARR , PERC H730P+ RAID Controller, 2Gb NV Cache, Adapter, Low Profile , DVD+/-RW , Dual, Hot-plug, Redundant Power Supply (1+1), 750W , Broadcom 5720 QP 1Gb Network Daughter Card, Ready Rails Sliding Rails With Cable Management Arm , 3Yr Basic Warranty - Next Business Day (Emerging Only) VCQM4000-PB NVIDIA Quadro M4000 8G. ❖ **Veeam Backup Enterprise** ❖ **Firewall Fg-80e-bdl** ❖ **Kaspersky Endpoint Security for Business Advanced** ❖ **PowerVault LTO-6** ❖ **IDRAC** ❖ **LTO-6 - 2.5TB tab * 12** ❖ **Windows Server 2016 Standard**			
6	**Server 02:**	Nos	1	DELL
	❖ **Dell power edge R330** Intel Xeon E3-1220 v6 3.0GHz, 8M cache, 4C/4T, turbo (80W), 32GB UDIMM, 2133MT/s, ECC, iDRAC8 Express, 3 x 1TB Near Line SAS 6Gbps 7.2K 3.5" Fully assembled (Hot Plug) Hard Drive, PERC H330 Integrated RAID Controller, DVD+/-RW, SATA, Internal, Single Hot Plug Power Supplies 350W, On-Board LOM 1GBE Dual Port , 3 year Basic Warranty. ❖ **Operating System**: Windows Server 2016 Standard			

	❖ **Protection**: Kaspersky Endpoint Security for Business Advanced ❖ **IDRAC**			
7	**Server Rack**	Nos	1	
	Minimum 32 U suitable for the server 01 and server 02, 1 top cover, 4 mounting profiles, 4 mounting angles, 2 fans, 1 fixed shelf, 1 tempered glass front door, 1 plain steel, rear door, 1 spring lock, 1 small lock, 2 removable side panels, 4 standard casters and 4 adjustable feet screws and nuts+2fan+1 fixed shelf- complete with monitor, keyboard and mouse			
8	**Wires and Cables**			
	Wires, cable, adapters			
B.) Software				
1	**Camera control module**			
	For web and desktop control, including capturing, shooting, time laps and event features.			
2	**Computer Vision Module**			
	For web and desktop platforms, including registration, calculating the progress, and tracking.			
3	**Automatic SMS and Notification Module**			
	For web and desktop platforms			
4	**Scheduling and Project Progress Module**			
	For web and desktop platforms, importing from Primavera, CSV, calculating progress using CPM			
5	**3D and 4D BIM Viewer**			
	Autodesk Revit and Navisworks			
6	**3D point cloud software**			
	Agisoft PhotoScan Pro			
7	**Programming project management software**			
	Primavera P6			

➢ **Step 3: Hardware Acquisition and Installation**

The hardware in Table 7. 1 was purchased, and accordingly the design camera locations and installation methods used are detailed hereinafter. The camera model used is shown in Figure 7.3.

7.1.4 Hardware and software

According to the site condition, the hardware designed was assembled in two independent sets as follows:

- The first is the “***camera set***”, which consisted of the camera, site WIFI mesh, network router, wires and cables; Figure 7. 4 shows the typical assembly for one of the installed camera sets with its hardware ancillaries.
- The second is the “***local server set***” which embraced server 1, server 2, UPS, the software, in addition to cables and adopters; Figure 7.5 shows the unit that contains the remaining hardware and software. The local server set was installed in an air-conditioned room to avoid any potential malfunctions due to heat, which can sometimes hit 55 C^{o} in Dubai during the summer session.

Figure 7.3: The used camera type before installation

Figure 7. 4: Camera set installed on freestanding mast

Figure 7.5: The local server set encompassed the used hardware and software

To test and verify the performance of the proposed prototype the system was initially developed in a real-life case study pilot project to monitor, control and update the progress.

According to IEEE STD-610., (2010, p.394) "*verification"* is the process of evaluating a system and corroborating by examination and provision of objective evidence, that the particular requirements for the specific intended use are fulfilled.

Consequently, verification of the prototype involved installation of cameras which were designed to capture images for the Reinforced Concrete (RC) columns. Only the RC columns superstructure were selected, mainly because it is easy to test the concept of a proposed prototype for one element initially, moreover, this construction element often forms part of the critical path.

Accordingly, any delay(s) for the superstructure were likely to affect the project adversely, thus leading to overruns.

Ensuring successful development of the prototype entails defining the following goals prior to starting the pilot project.

The predefined goals of the pilot project:

A. The main purpose of this pilot project is to proof the concept of the proposed prototype.
B. To test, evaluate and verify the effectiveness of the developed prototype, by the management team of the pilot project.
C. Allow for developments, amendments, and iterative revisions on the prototype.
D. Develop a ready to use automated system to detect delays and send timely automatic notifications to support decision-makers.

Once the concept is proven, the sphere will be broadened to include all the construction elements such as foundations, beams, slabs, walls, etc., which will be further tested and validated in a full project life-cycle case study in chapter 8.

➢ **Step 4: Data Acquisition**

Acquiring authentic data from the site is the mainstay of the system and acquired data represents the progress status (i.e. the as-built).

Thus, the installation design of the cameras considered capturing all the details of the RC columns. As shown in Figure 7.6, the cameras were positioned to cover all the construction details for the RC columns. In order to collect data from the construction site, moreover, cameras were programmed to capture images daily at 5:00 PM after the site shut down; the captured image at this time represented the progress accomplished at the end of the day. Capturing images is an automated process that was repeated daily, except on Friday which is the weekend in Dubai.

7.1.5 Camera installation

The design of the Terrestrial Data Capture System (TDCS) demonstrated in Figure 7.6 shows the locations of each camera. The interactive Excel sheet for TDCS/distance calculator is included in Appendix 5, the design determined the maximum distance that allows for the capture of clear photos, for this site is 52.00 m, measured from the camera to the object.

Moreover, the design determined the installation of four cameras, however; to ensure continuous data acquisition without interruption, an additional camera was fixed according to the following details.

According to the site conditions, there were two methods followed for camera installation as follows:

i. Four cameras were installed on four freestanding masts as shown in Figure 7.7, to cover the full height of the building which is 18.5 metres, as measured from the asphalt of the road, and to capture all the details of the RC columns. The four cameras were installed on a 25^{o} goose neck short pole measured from the vertical line as shown in Figure 7.7. The coordinates (x, y, z) for these cameras were accurately determined.

ii. The additional camera was installed on the trolley pulley of the tower crane jib. This method of installation allowed this camera to capture images with two degrees of freedom.

    The first degree of freedom allowed the camera to slide on the longitudinal direction along the crane boom as shown in the below Figure 7. 8; *the second free* movement was the normal rotational motion of the jib in the horizontal direction.

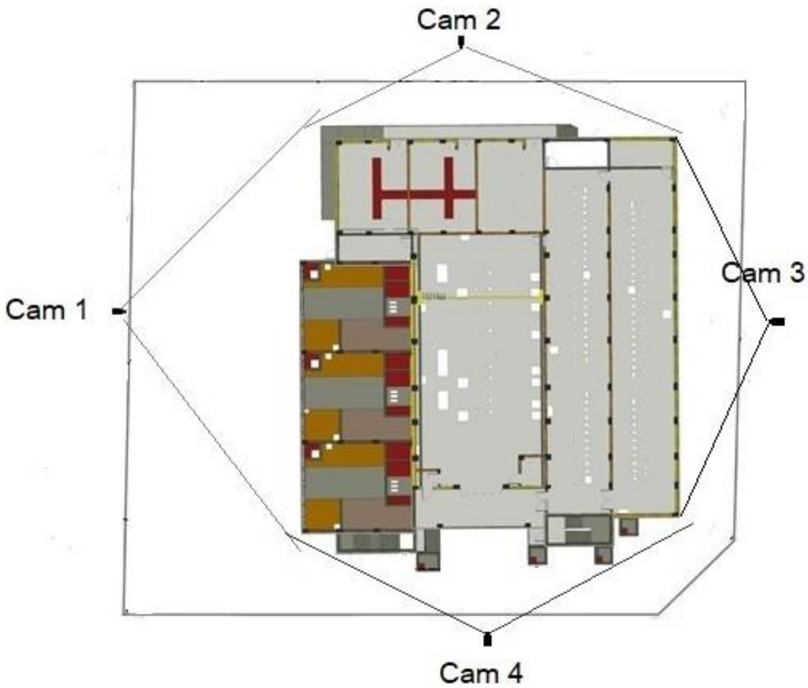


Figure 7.6: Camera positions with Field Of View, (dotted lines are FOV)

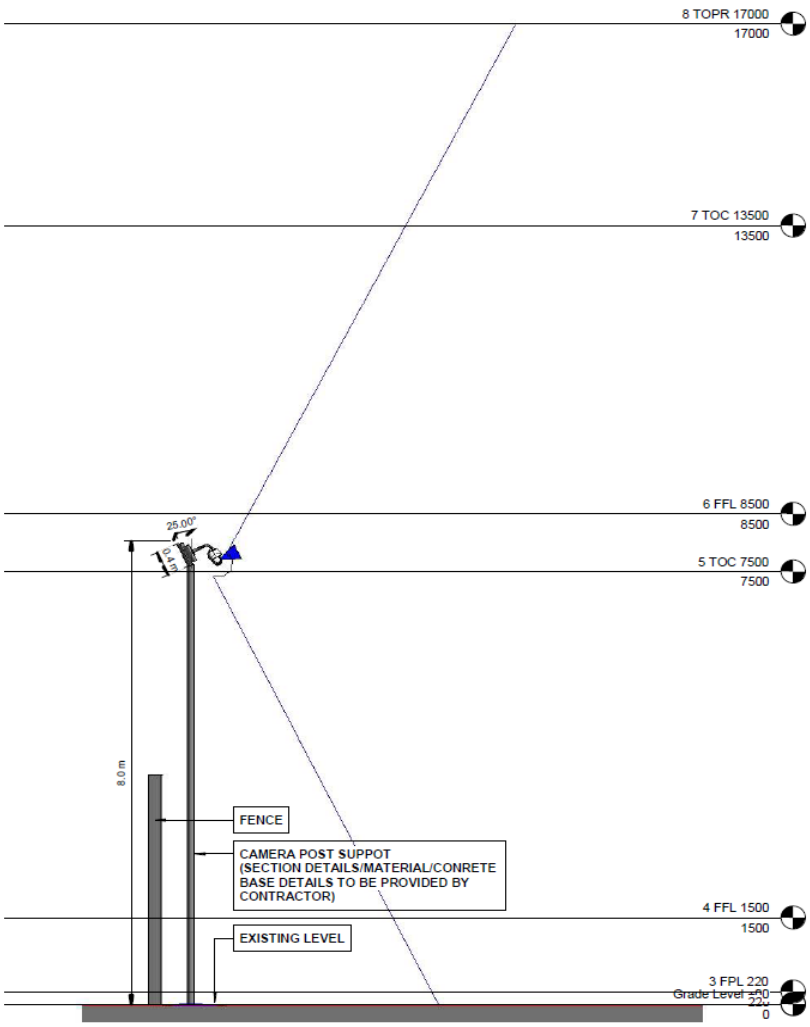


Figure 7.7: Camera installed on freestanding mast

Figure 7. 8: Camera installed on the tower crane

Surprisingly, the additional camera that was installed on the tower crane succeeded in acquiring all details of the RC columns. However, to fully ensure all details are acquired from the site, the five cameras operated together to capture the details of RC columns at the predefined daily event.

The capturing process from the tower crane camera differs from the other four cameras, whereas, the tower crane camera was designed to work during the last two hours of each working day. It was designed to capture an image every one and half minute for two hours at the end of each working day (i.e. starts at 3:00 PM till 5:00 PM).

The blue spots shown in Figure 7.9 and Figure 7.10 illustrate the camera positions from two different directions on the building, and according to the above mentioned two degrees of freedom of the camera designed for crane movements. The blue coloured spots indicate the camera positions while shooting the images; one position (i.e. blue spot) represents the position for capturing one image.

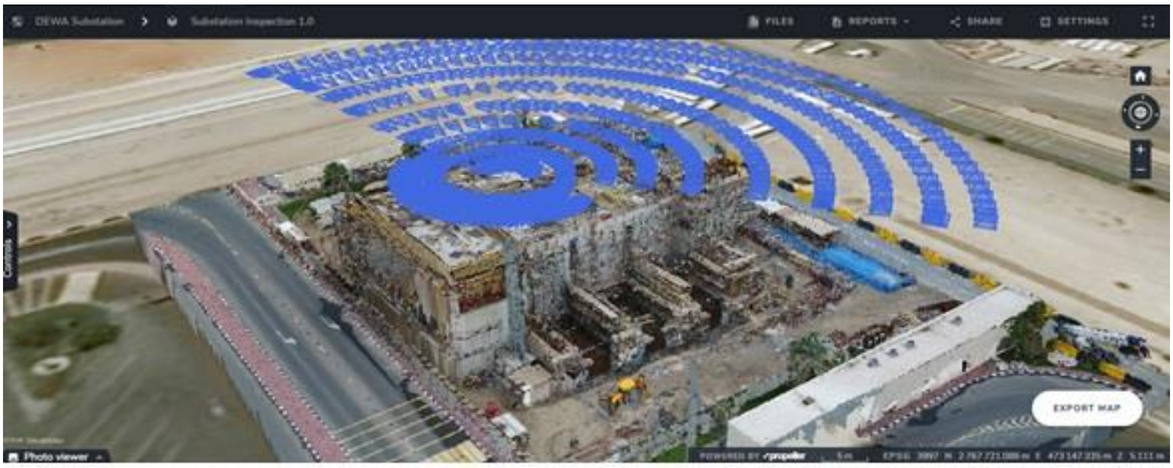


Figure 7.9: Blue spots represent positions of the camera during shooting, North direction

Figure 7.10: Blue spots represent positions of the camera during shooting, South direction

The number of images captured daily from just the camera installed on the tower crane was 120; these images encompassed all required details of the RC columns.

However, the other four cameras captured 320 images in two hours (one image every 1.5 minutes). Consequently, the total number of all the captured images was approximately 440 a day.

According to the design of the terrestrial data capture and to ensure all the construction details are covered, cameras 1 and 3 were programmed to capture images every 3 degrees in the horizontal direction, and 4 degrees in the vertical direction.

However, cameras 2 and 4 captured images every 2.5 degrees horizontally and 4 degrees vertically. Indeed, these horizontal and vertical movements of the four cameras have replaced the need for 28 stationary cameras, which would have been installed at three different levels on the freestanding masts (i.e. 3m, 5m and 10m height measured from the ground level).

In other words, the tilting feature of the four cameras utilised have counteracted the need of 28 cameras installed in static mode.

7.1.6 Camera calibration

Once the cameras were installed on site, they must be calibrated prior to initiating the capture of images. The camera calibration process is the mainstay for correct data abstraction, as it enables determination of the accurate relationship between each object in the image and its physical representation (Zhang, 2000; Dong *et al.,* 2016; Percoco *et al*., 2017; Tan *et al*., 2017).

Traditionally, building a 3D point cloud model originating from images from a camera required the installed cameras to cover the target objects from different angles (Detchev *et al.*, 2014). The captured images used to construct 3D point models included enough detail to measure the dimensions and coordinates of the 2D images. Consequently, poor calibration of a camera will result in blemished images, such as distortions, which in turn can affect the reliability and accuracy of the extracted information. Therefore, camera calibration tends to be the most crucial process for any computer vision application (Percoco *et al*., 2017; Fetić *et al.,* 2012).

Tan *et al.,* (2017) concluded that there are two main techniques to calibrate cameras: the first is "***photogrammetric calibration"***, which requires prerequisite knowledge of the physical object such as its dimensions, coordinates and directions, in addition to the 2D information from the captured image.

The second is “***self-calibration”*** which does not require any prerequisite knowledge.

Empirically, using the first approach will give more reliable and accurate data compared with the second approach, as utilising advanced knowledge reduces the number of parameters (Tan *et al*., 2017).

Therefore, this research selected the *photogrammetric calibration* approach using the checkerboard 9×6 with a known pattern, size and structure as shown in Figure 7.11.

To ensure cameras have the same geometrical representation of the captured scene, cameras were calibrated by shooting 32 images from different positions for the checkerboard Figure 7.11. These images were uploaded to MATLAB R2018b to determine the intrinsic (focal length, principal point, lens distortion coefficient) and extrinsic parameters of the cameras which concerns calculation of the position and orientation of the camera with respect to the global reference (Escalera and Armingol, 2010).

In this process, once the 32 images were uploaded to MATLAB toolbox; the software recognised automatically the corner points of the checkerboard Figure 7.12. Subsequently, to determine the intrinsic and extrinsic parameters, MATLAB toolbox re-projected the corners to determine the re-projection errors Figure 7.13 (Fetić *et al*., 2012).

During the calibration process, the following measures were considered:

1. Obtaining the optimum and clear view of the checkerboard, with minimum camera magnification to reduce blurred images (Percoco et al., 2017).
2. The Angle Of View (AOV) and Depth Of Field (DOF) were calculated to attain a minimum of 75% side and forward overlap for consecutive shots.
3. The control point pattern of the checkerboard was well known and manufactured accurately.
4. The calibration process was iterated a total of 6 times to acquire the best result by reducing the errors for the determined parameters Figure 7.14 and Figure 7.15.

The following parameters were produced to provide optimal results for building the 3D point cloud model with accurate and reliable details:

- Focal length is 50mm, which was also recommended by (Agisoft PhotoScan Pro user manual, 2017, p.7).
- The maximum distance from object is 52 m.
- Angle for camera to capture photos ±45º from the horizontal axes.
- Ground Sampling Distance (GSD) width is 0.2038 and height 0.2044 (cm/pixel).

Some important definitions for the abovementioned terms can be found below:

AOV is a measure of how much of scene the lens can view, in degrees (Tim 2013, p. 289).

FOV is defined as a measurement indicating how much of a scene can be viewed through a particular lens. The term FOV is often used interchangeably with AOV even though they are technically not the same (Tim 2013, p. 289).

DOF is the range of distances within which objects are captured with acceptable sharpness (Nanette 2009, p. 110).

GSD is the proportional ratio between the pixel size on the image and the object dimensions (Felipe-García and Hernández-López, 2012).

Focal length is an optical property that allows the camera to measure the distance in millimetres; it is measured from the lens's optical centre to the camera's sensor (Kaye, 2009).

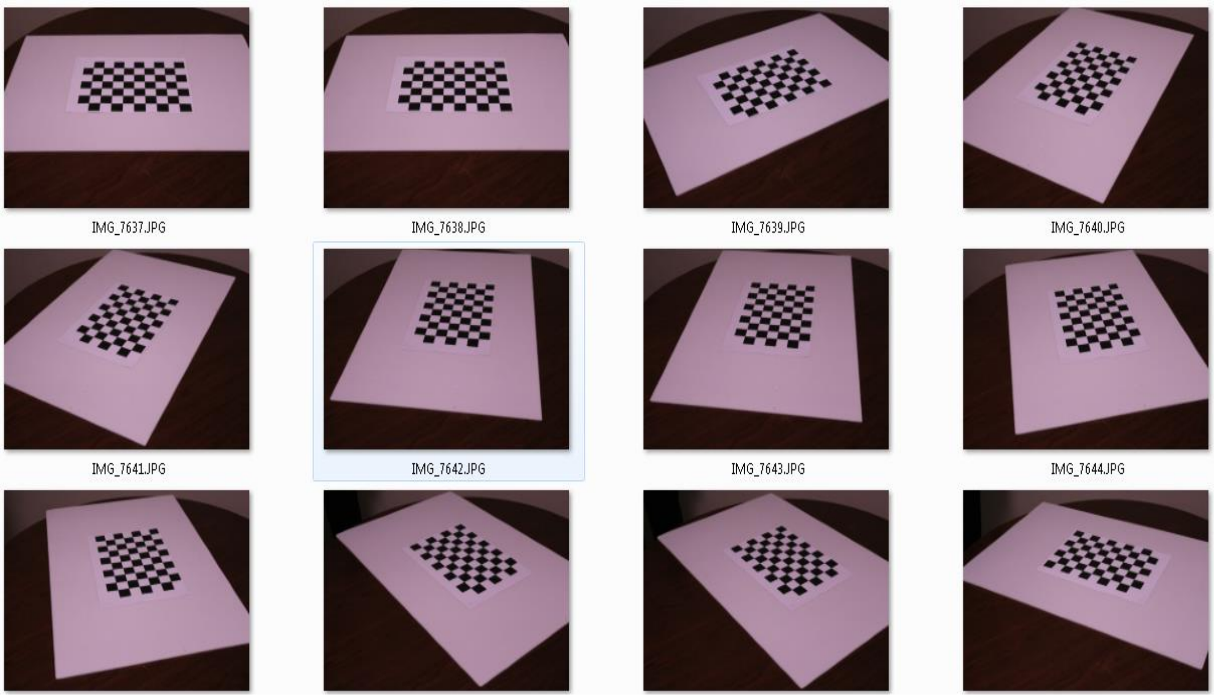


Figure 7.11: Images captured for 9×6 planar checkerboard used for camera calibration

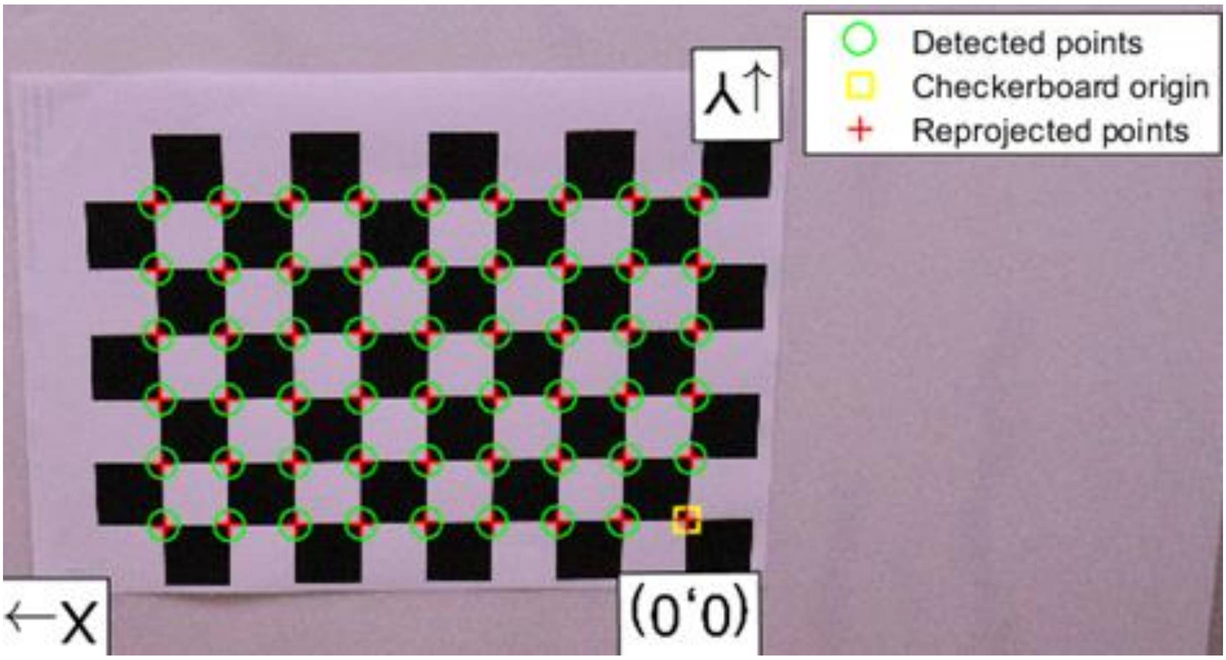


Figure 7.12: The centre of the circle demonstrates images' detected corners and the red-cross intersection re-projected the corners using the calibrated camera parameters

Figure 7.13: Reprojection error is the offset from the circle center to the cross intersection

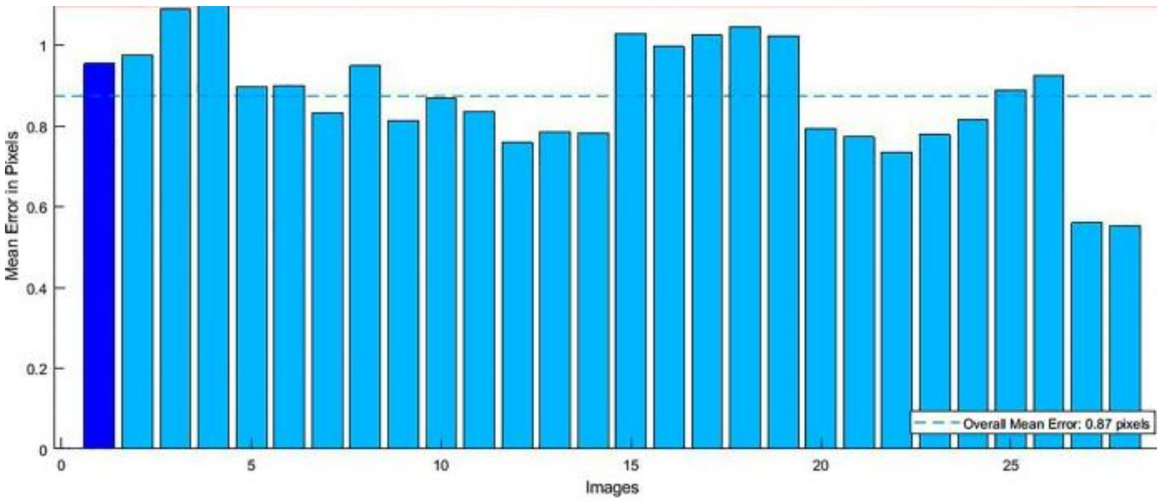


Figure 7.14: High re-projection mean error (0.87pixels)

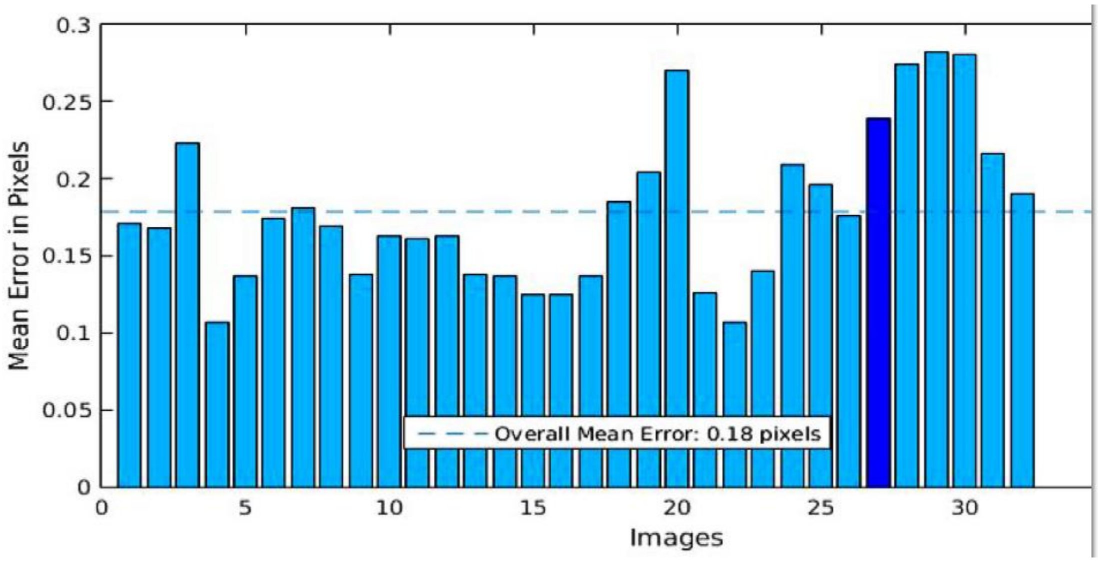


Figure 7.15: Adjusted re-projection mean error (0.18 pixels)

7.1.7 Occlusions

One of the most challenging issues encountered in the implementation of this system is related to occlusions. As a reminder, an occlusion is defined as any blockage of the camera vision by a physical object (Chi and Bisheng, 2016).

An occlusion can be classified into two main categories based on its source, ***static occlusion*** which is a result of a static object (such as scaffolding, steel rebar, timber, etc.), and ***dynamic occlusion*** which is a result of movable objects (such as labourers, machines, etc.). Indeed, it is extremely difficult to obtain a clear image without occlusions Figure 7.16. On a construction site, occlusions are often inevitable (Ibrahim *et al*., 2009; Dimitrove and Gloparvar-Fard, 2014).

Figure 7.16: Construction site image shows static and dynamic occlusions due to daily construction activities

To remove the risk of dynamic occlusion, it was decided to capture site images at 5:00pm after the site closes of the day. This carefully selected time significantly reduced the dynamic occlusions on captured images because the site is shut down; accordingly, there are no active labourers or machines.

Although 60% side overlap is recommended by Agisoft PhotoScan Pro (Agisoft Agisoft PhotoScan, 2017, p.8), it was decided to consider a 75% side overlap for captured photos to ensure the same object has at least 3 photos from different viewing positions. This process enabled the software to automatically remove any dynamic occlusion by applyinga simple background-foreground subtraction from the 2D images (Nguyen and Smeulders, 2006; Chi and Bisheng, 2016; Sengar and Mukhopadhyay, 2017; Agisoft PhotoScan Manual, 2017).

According to Bouwmans *et al.,* (2017) and Chiu *et al.,* (2018) simple background-foreground subtraction is a process wherein the built-in algorithm via the software detects and segments the moving objects. The moving objects are referred to as “foreground” and the surrounding static information referred to as “background”. The algorithm detects the difference between the background and foreground to process the subtraction which results in images clear from any moving object.

A sample of the automatic removal of dynamic occlusions by applying a simple background-foreground subtraction from the 2D images is shown in Figure 7.17 and Figure 7.18.

In Figure 7.17 one labourer in a yellow uniform can be seen moving from left to right in addition to two labourers wearing orange represent dynamic occlusions captured in three consecutive images. These three images in addition to other images were used to build the 3D point cloud model shown in Figure 7.18. The Agisoft software built the point cloud after cleaning the dynamic occlusion of the three labourers, *because* the software functionality mechanism for simple background-foreground subtraction works in a way that, during stitching the images to build the point cloud model. If the dynamic occlusion (movable objects) are detected in one image and not detected in the same position (pixel) in the consecutive image(s); accordingly, the software only considers the images which are free from dynamic objects, provided that, at least 60% side overlap is achieved for the consecutive images (Agisoft LLC, 2017; Al-Smadi *et al.,* 2019).

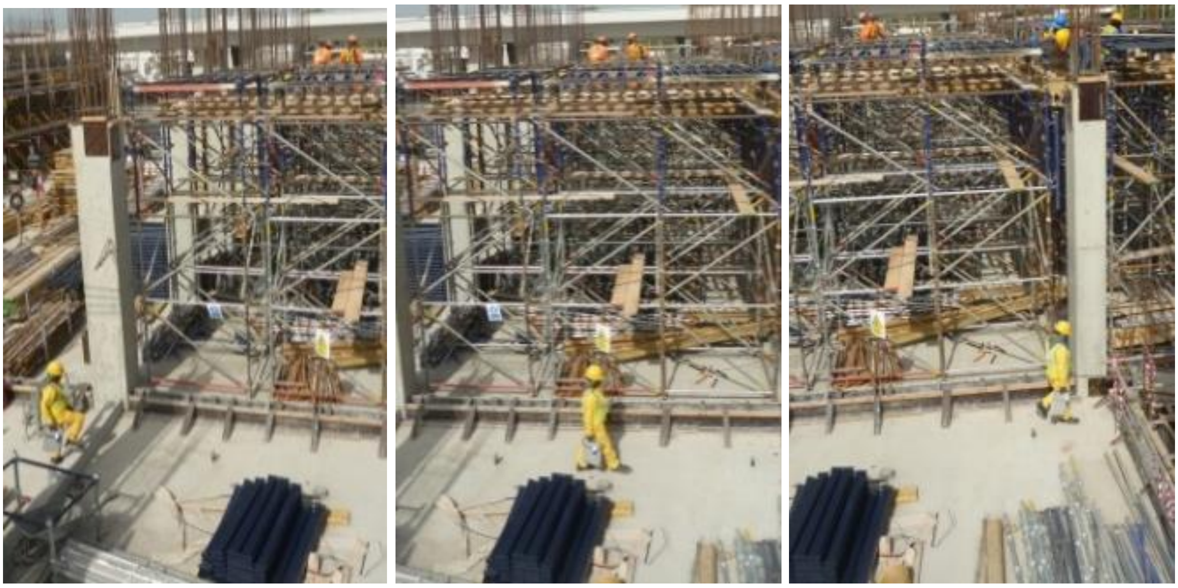


Figure 7.17: Sample of captured site photos with dynamic occlusions used to construct point cloud model

Figure 7.18: Point cloud built from captured photos for columns (cleaned from dynamic occlusion)

However, static objects usually occlude camera vision in two forms, either partially or fully. Full occlusion is defined as any action that precludes camera to capture photo(s) of the target object (Chi and Bisheng, 2016). Full occlusion was deemed beyond the scope of this research as it often requires training a 'Machine Learning' classifier to clean the occlusion.

However, monitoring construction sites is largely concerned with static partial occlusion (Guan *et al.,* 2006; El-Omari and Moselhi, 2008; Omar *et al.,* 2018), partial occlusion is the most common issue in construction projects, which is dealt with by the development of algorithms in the following section. The proposed prototype put forward a technique to reduce the impact of the partial static occlusion that usually occurs at construction sites, particularly for vertical elements. Whereas – by default – the progress for concrete elements, such as columns, walls, beams and also the brickworks are vertical, however, the cross-sectional area is known from the BIM model.

As a result, the most important part for the camera to capture is the casted height; which is obtained by applying the hereinafter algorithms 3 and 4. The outputs from algorithm 4 are effective even with partial occlusion, provided that the last part of the element (i.e. the vertical tip of the construction element) is detected in the image.

7.1.8 Algorithms to detect delays

In order to automatically detect any discrepancies between as-planned and as-built progress status, five algorithms were developed. Whereby the first algorithm prepares cleaning and removal for unnecessary points from the 3D built cloud model for the construction element. And then second algorithm aligns the built 3D point cloud model with the BIM model to allow removal of occlusions by using the third algorithm. However, the fourth algorithm calculates the area, volume, quantity according to the construction schedule quantifications. Ultimately, the fifth algorithm determine the progress status compared with the as-planned and develop the results in percentage to allow further notifications via SMS and emails to the project stakeholders.

The following section considered the column as an example for explaining the functionality of the developed algorithms; however, the same algorithms can be applied to any construction element.

7.1.8.1 Algorithm 1: registration of virtual surfaces for the 3D BIM model

The aim of this algorithm is to create internal and external boundaries/surface planes as shown Figure 7.19, and incorporate them into bounding boxes. These created bounding surfaces contain the construction element, so as to isolate the points relevant for each element and enable processing later. It uses the element surfaces modelled within the 3D BIM model from 6 directions (top, bottom, left, right, front and back), and then simply adds displacements of 5mm to each in each direction (external and internal). The result is a pair of surfaces for each of the 6 sides, containing all relevant point cloud points.

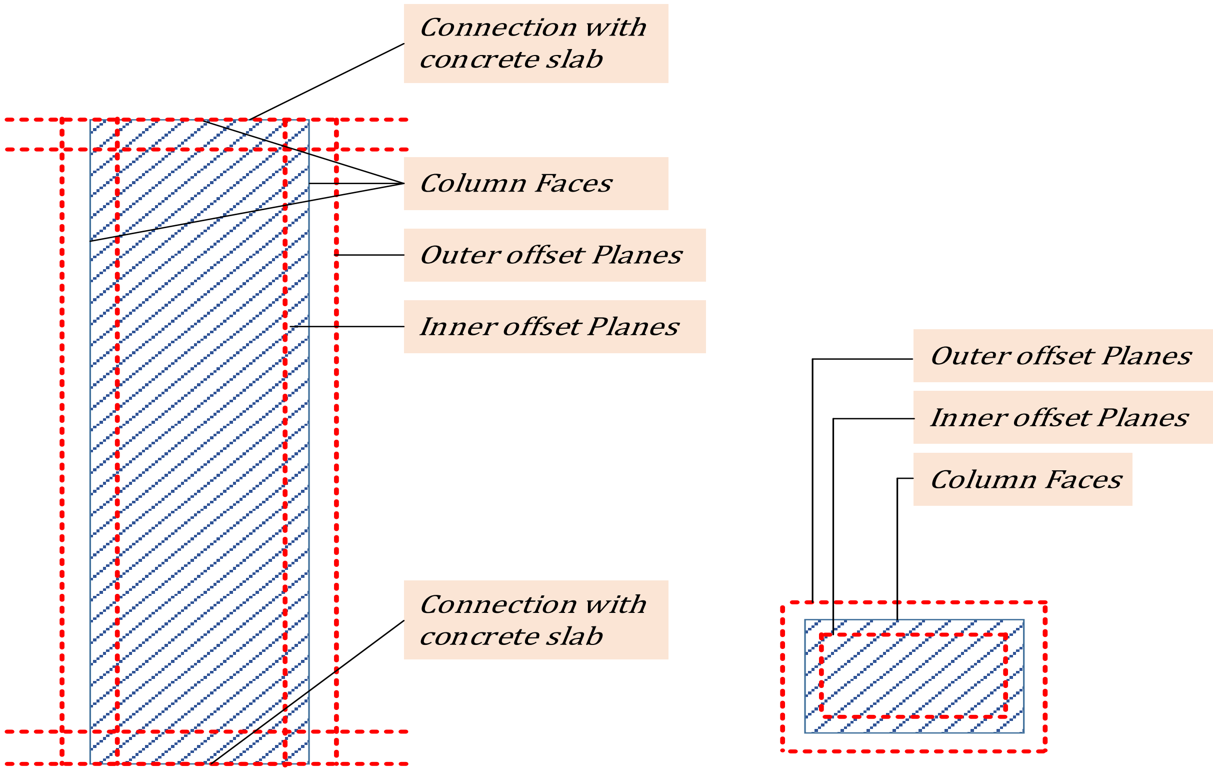


Figure 7.19: creating virtual internal and external surface planes

Algorithm 1:

Input

- Construction element from 3D BIM model
- Construction element surfaces (*S0, S1, S2.... S5)*
- Displacement offset distance *Doffset*

1. Recognise construction element original faces (*S0, S1, S2.... S5)*
2. Add external planar surface surrounding the construction element with offset= *Doff1*

   Doff1= (Se0+5mm,...., Se5+5mm)
3. Identify intersections between planar surfaces *(Se0, Se1,.., Se5)*
4. Combine planar surfaces *(Se0, Se1,.., Se5)*
5. Add internal planar surface surrounding the construction element with offset *Doff2*

   Doff2= (Si0+5mm,..., Si5+5mm)
6. Recognise intersections between planar surfaces *(Si0, Si1,.., Si5)*
7. Combine planar surfaces *(Si0, Si1,.., Si5)*

Output

- Column in 3D BIM model surrounded with additional external and internal surfaces
- External surfaces *(Se0, Se1, Se2.... Se5)* Figure 7.20a
- Internal surfaces *(Si0, Si1, Si2.... Si5)* Figure 7.21b

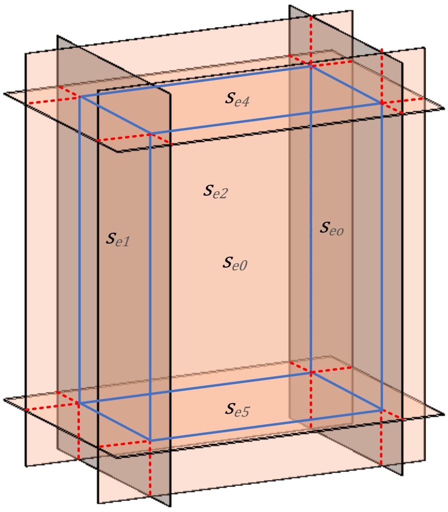


Figure 7.20a: Creating virtual external surface planers

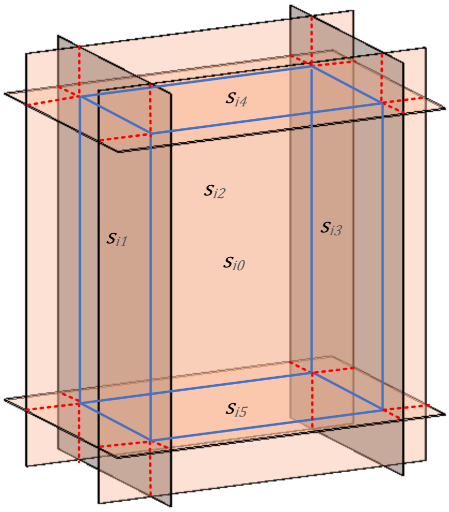


Figure 7.210b: Creating virtual internal surface planers

7.1.8.2 Algorithm 2: Aligning the 3D Point Cloud model with the 3D Construction element from the BIM model

This algorithm seeks to align the two models i.e. the 3D point cloud model developed by Agisoft PhotoScan pro and 3D BIM model with external and internal surface planes from algorithm 1. The coordinates for each camera was precisely estimated. Accordingly, the projection of the coordinates on the 3D point cloud model were introduced only once by matching at least four coordinates in both models to ensure the reference points in both models are precisely synchronised.

<u>**Algorithm 2**</u>

Input

- Internal offset planes *(Si0, Si1, Si2,...., Si5)*
- External offset planes *(Se0, Se1, Se2,...., Se5)*

1. Origin Apj is the mean point in 3D

   $Apj = \frac{1}{n}\sum_{i}^{n}(Xi, Yi, Zi)$

   n = number of points *(Xi, Yi, Zi)* in point cloud shaping the construction element
2. Define construction element origin in BIM model *Am*
3. Translate the point cloud origin Apj to the construction element origin *Am*
4. Compute transformation *(R, T)*

   R=3D rotational angle

$T=3D$ translation

5. Apply the transformation (R, T) to the point cloud origin Apj towards Am in BIM model
6. Calculate error matrix
7. Iterate to minimise the error
8. Apply stopping criteria at error ≈ 0

Output

- Aligned 3D point cloud to the 3D BIM model.
- Point Cloud Transformations (R, T) are known.

7.1.8.3 Algorithm 3: Determine construction element point cloud and remove occlusions

This algorithm performed a removal of clutters and occlusions to consider only the points which represent the as-built progress update for construction element(s). This algorithm filters the points in the point cloud by confining these points between the external and internal surface boundaries in algorithm 2.

Algorithm 3

Input

- External surfaces $(Se0, Se1, Se2.... Se5)$
- Internal surfaces $(Si0, Si1, Si2.... Si5)$
- Aligned point cloud Pc with 3D BIM model

1. $(Pn, P0, P1) \in Pc$

   Pn Represents points outside the surface boundaries Figure 7.22

   $P0$ Represents points located within the surface boundaries (between internal and external)

   $P1$ Represents points located within internal boundary only
2. For every point $p \in P_c$:

   If p is between S_{i0} and S_{e0}, or S_{i1} and S_{e1}, or … S_{e0} and S_{i5}

   Register $p \in P_0$
3. For every point $p \in P_c$:

   If p is between S_{i0} and S_{i5} (front and back internal surfaces)

   Register $p \in P_1$
4. For every point $p \in P_c$:

   If $p \notin P_1$ and $p \notin P_0$

   Register $p \in P_n$
5. Report column point cloud $P0$, algorithm stops.

Output

- Confined point cloud *P0* between internal and external surface boundaries Figure 7.22.
- 3D point cloud with cleared from clutter and occlusion.

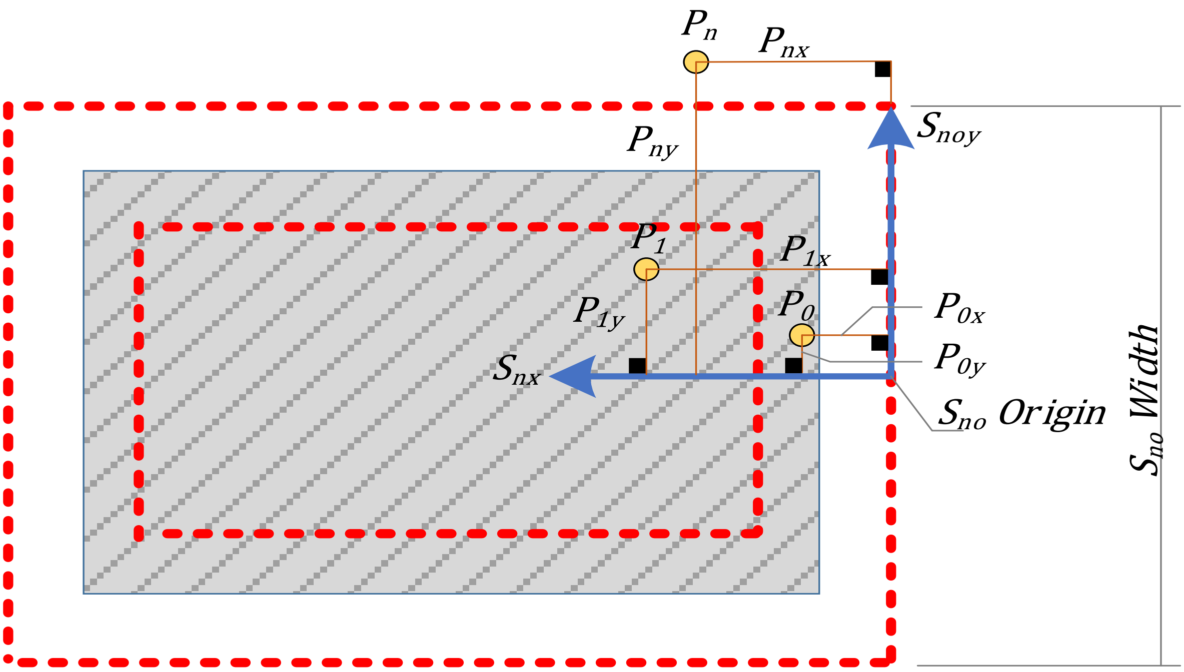


Figure 7.22: Points are determined within the surface boundaries, according to algorithm 1

7.1.8.4 Algorithm 4: Calculation of the progressive construction element volume

The aim of this algorithm is to determine the as-planned volume of concrete for each column, by measuring the true column heights H (maximum heights) obtained from the point cloud in algorithm 3. To obtain the column's progressive volume arithmetic, multiplication ($H \times A$) is applied where A is the cross-sectional area of the construction element. The algorithm starts by calculating the maximum height of the point cloud confined between the internal and external boundaries. Height calculation starts from the lower surface and progressively increases the height by a constant value of 10 millimetres. The existence and density of the points are then computed.

Algorithm 4

Input

- 3D BIM Column cross sectional area A
- Column with point cloud density *P0*

1. Algorithm starts by counting points of point cloud at
   $\{h_i\} = \{0, 10, 20, 30, \ldots\ldots mm\}$,
   Where $h_{i+1} = h_i + 10mm$, representing height above predefined coordinates of the column *(0, 0, 0)*.

2. Set $i = 0$
3. Calculate point cloud density, T_i in cross section at height h_i
4. Evaluate stopping criterion; $T_i < \varepsilon T_{i-1}$, where $\varepsilon = 0.8$, indicating a sharp decrease in density due to T_i being outside the body of the construction element.
5. If FALSE: set $i = i + 1$; go to 3. Else continue.
6. Set construction element height $H = h_{i-1}$
   - The construction element height H considered from the predefined coordinate *(0,0,0)*
7. Compute construction element volume Vj

   $Vj = H \times A$

   A is the construction element's cross sectional area

   $A = W \times L$

   W is the construction element width from BIM model

   L is the construction element length from BIM model

   $\therefore Vj = H \times W \times L$

Output

- Point cloud height represents the true progress of the concrete element.
- As-built progressive volume for any construction element.

7.1.8.5 Algorithm 5: Computations for the progress through detection of delays by comparing the as-planned schedule against the as-built status

After algorithm 4 the calculated as-built volume requires to be compared with the 4D BIM model based on the date to determine the progression percentage against the as-built percentage and further calculate the variance in percentage.

Algorithm 5

Input

- The calculated volume, area, number that reflects the as-built status
- 4D BIM model

1. Recognise the date from the calendar
2. Acquire the respective construction object O based on its predefined ID
3. Define as-planned progression percentage for $O1p$
4. Define actual progression percentage for $O1a$

5. Calculate $\frac{O1a - O1p}{O1p} \times 100\%$

6. Show the results as a percentage in three figures, as-planned, as-built, variance

7. End.

Output

- Percentage of as-planned progress
- Percentage of as-built progress
- Variance in percentage between the as-planned and as-built progress

7.1.8.2 Sample of programming codes for the developed automated system

...3_190923\02-Modules\M205x0201xHIKCORxD1CP\Core\Camera.cpp 1

```cpp
#define _CRT_SECURE_NO_WARNINGS

#include "Camera.h"
#include <iostream>
//#include <stdio.h>
//#include "Windows.h"
//#include "string.h"
#include "HCNetSDK.h"

namespace M205x0201xHIKCORxD1CP
{

    typedef HWND(WINAPI *PROCGETCONSOLEWINDOW)();
    PROCGETCONSOLEWINDOW GetConsoleWindowAPI;
    typedef void(*Callback)();
    Callback Camera::MotionDetectionCallBack;
    const char* Camera::msg;

    Camera::Camera(const char* name, const char* ip, float diviceport, const char* username, const char* password) :
        m_name(name), m_ip(ip), m_diviceport(diviceport), m_username(username), m_password(password)
    {
        int i = 0;
        BYTE byIPID, byIPIDHigh;
        int iDevInfoIndex, iGroupNO, iIPCh;
        DWORD dwReturned = 0;
        m_dwCount = 1;
        //---------------------------------------
        // Initialize
        NET_DVR_Init();
    }

    void Camera::SetOnMotionDetectionCallBack(Callback callback)
    {
        MotionDetectionCallBack = callback;
    }

    void Camera::OnMotionDetection()
    {
        MotionDetectionCallBack();
    }
    void CALLBACK MessageCallback(LONG lCommand, NET_DVR_ALARMER *pAlarmer, char *pAlarmInfo, DWORD dwBufLen, void* pUser)
    {
        int i;
        NET_DVR_ALARMINFO struAlarmInfo;
        memcpy(&struAlarmInfo, pAlarmInfo, sizeof(NET_DVR_ALARMINFO));

```

```
        switch (struAlarmInfo.dwAlarmType)
        {
        case 3:
            if (Camera::MotionDetectionCallBack!=nullptr)
            {
                try
                {
                    Camera::MotionDetectionCallBack;
                }
                catch (const std::exception& ex)
                {
                    Camera::msg = ex.what();
                }
                Camera::msg = "Motion Detected";
            }
            else
                Camera::msg = "Motion Detected & call back is null!!!";

            break;
        default:
            break;
        }
    }

    int Camera::SetMotionDetection()
    {
        //NET_DVR_SetDVRMessageCallBack_V30(MessageCallback, NULL);


        //Enable arming
        LONG lHandle;
        lHandle = NET_DVR_StartListen_V30(NULL, 7200, MessageCallback, NULL);


        //Arming parameter
        NET_DVR_SETUPALARM_PARAM  struAlarmParam = { 0 };
        struAlarmParam.dwSize = sizeof(struAlarmParam);
        struAlarmParam.byAlarmInfoType = 0;
        //Judge whether the device supports the new alarm information via the parameter bySupport1 & 0x80 in the NET_DVR_DEVICEINFO_V30 returned after login.

        //lHandle = NET_DVR_SetupAlarmChan_V30(_lUserID);
        if (lHandle < 0)
        {
            printf("NET_DVR_SetupAlarmChan_V30 error, %d\n", NET_DVR_GetLastError());
            NET_DVR_Logout(_lUserID);
            NET_DVR_Cleanup();
```

```

            Camera::msg = "Handle is less than zero";
            return -1;
        }
        else
            Camera::msg = "Handle is correct!";

        return 0;
    }

    int Camera::Login()
    {
        Camera::msg = "Login_started";
        int i = 0;
        BYTE byIPID, byIPIDHigh;
        int iDevInfoIndex, iGroupNO, iIPCh;
        DWORD dwReturned = 0;

        //---------------------------------------
        // Initialize
        NET_DVR_Init();
        //set connected time and reconnected time
        NET_DVR_SetConnectTime(2000, 1);
        NET_DVR_SetReconnect(10000, true);

        //---------------------------------------
        // Register device
/*      LONG lUserID;*/

        //Login parameters, including IP address, user name, password and so
          on.
        NET_DVR_USER_LOGIN_INFO struLoginInfo = { 0 };
        struLoginInfo.bUseAsynLogin = 0; //Synchronous login mode
        strcpy(struLoginInfo.sDeviceAddress, m_ip); //IP address
        struLoginInfo.wPort = m_diviceport; //Service port
        strcpy(struLoginInfo.sUserName, m_username); //User name
        strcpy(struLoginInfo.sPassword, m_password); //Password

                                                     //Device information,
                    output parameter
        NET_DVR_DEVICEINFO_V40 struDeviceInfoV40 = { 0 };

        _lUserID = NET_DVR_Login_V40(&struLoginInfo, &struDeviceInfoV40);

        //Set alarm callback function
        NET_DVR_SetDVRMessageCallBack_V30(MessageCallback, NULL);

        //Enable arming
        LONG lHandle;
```

```cpp

        //Arming parameter
        NET_DVR_SETUPALARM_PARAM  struAlarmParam = { 0 };
        struAlarmParam.dwSize = sizeof(struAlarmParam);
        struAlarmParam.byAlarmInfoType = 0;
        //Judge whether the device supports the new alarm information via the parameter bySupport1 & 0x80 in the NET_DVR_DEVICEINFO_V30 returned after login.

        lHandle = NET_DVR_SetupAlarmChan_V41(_lUserID, &struAlarmParam);

        if (_lUserID < 0)
        {
            printf("Login failed, error code: %d\n", NET_DVR_GetLastError());
            NET_DVR_Cleanup();
            m_lastError = NET_DVR_GetLastError();
            return -1;
        }

        return 0;
    }



    int Camera::Logout()
    {
        //User logout
        BOOL result = NET_DVR_Logout(_lUserID);
        //Release SDK resource
        NET_DVR_Cleanup();

        if (result)
            return 0;
        return -1;
    }

    int Camera::StartPlayBack(HWND hWnd)
    {
        _hWnd = hWnd;
        NET_DVR_PREVIEWINFO struPlayInfo = { 0 };
        struPlayInfo.hPlayWnd = _hWnd;          //Set the handle as valid when the stream should be decoded by SDK, while set the handle as null when only streaming.
        struPlayInfo.lChannel = 1;        //Live view channel No.
        struPlayInfo.dwStreamType = 0;  // 0 - Main Stream, 1 - Sub - Stream, 2 - Stream 3, 3 - Stream 4, and so on.
        struPlayInfo.dwLinkMode = 0;        //0-TCP Mode, 1-UDP Mode, 2-Multi-play mode, 3-RTP Mode, 4-RTP/RTSP, 5-RSTP/HTTP
        struPlayInfo.bBlocked = 1;        //0-Non-Blocking Streaming, 1-Blocking
```

```
            Streaming

        _realPlayHandler = NET_DVR_RealPlay_V40(_lUserID, &struPlayInfo, NULL, NULL);
        //SetMotionDetection();
        if (_realPlayHandler < 0)
        {
            printf("NET_DVR_RealPlay_V40 error\n");
            NET_DVR_Logout(_lUserID);
            NET_DVR_Cleanup();
            return -1;
        }


        return 0;
    }

    int Camera::StopPlayBack()
    {
        //Stop live view
        BOOL result = NET_DVR_StopRealPlay(_realPlayHandler);
        if (result)
            return 0;
        return -1;
    }

    int Camera::GotoPreset(float presetIndex)
    {

        BOOL result = NET_DVR_PTZPreset(_realPlayHandler, 39, presetIndex);

        if (result)
            return 0;
        return -1;
    }
    int Camera::SetPreset(float presetIndex)
    {

        BOOL result = NET_DVR_PTZPreset(_realPlayHandler, 8, presetIndex);

        if (result)
            return 0;
        return -1;
    }
    int Camera::DeletePreset(float presetIndex)
    {

        BOOL result = NET_DVR_PTZPreset(_realPlayHandler, 9, presetIndex);

```

Additional codes are included in Appendix 6.

7.1.9 Prototype functionality via Computer Vision based close-range photogrammetry

In the last two decades, building accurate 3D models from 2D images has attracted considerable attention. The constructed 3D model is used in several fields such as monitoring construction activities (Kwak *et al*., 2013; Han *et al*., 2017).

The proposed system will be referred to hereinafter as AMAC; AMAC is abbreviated term for **A**utomatic **M**onitoring **A**nd **C**ontrolling system.

Functionality of AMAC system is explained according to the processes in Figure 7. **23**, wherein AMAC was designed as a fully automated system, for which a close-range photogrammetry technique was employed to collect images from the construction site using the five installed cameras (*process A,* Figure 7. 23).

The daily acquired images were registered automatically, through the creation of a folder; this folder stores the captured images for its event in the local server as shown in Figure 7.24.

And thereof these images were amalgamated after removing the erratic images (*process B*); Agisoft PhotoScan Pro software has a built-in feature to recognise and exclude any erratic image(s). This process is so called the registration of images.

Subsequently, the registered images are exported automatically to Agisoft PhotoScan Pro software to stitch the images (*process C*). Although Agisoft PhotoScan Pro recommended 40 images as the minimum number for building the 3D point cloud model, the daily captured images were 440 of which in average 395 images registered as true images to construct the 3D point cloud model. According to Agisoft PhotoScan Pro (2017, p.8) to build the point cloud from images, the greater number of photos than required is better than the less.

Afterwards, the software constructs the 3D point cloud model from the registered images as shown in Figure 7.18 (*process D*). Removal of dynamic occlusions is achieved via the built-in feature of Agisoft PhotoScan Pro software which allows automatic removal of the dynamic occlusions as shown in Figure 7.17 and Figure 7.18 (*Process E)*.

Additionally, the developed algorithms from 1 through 3 are used to reduce and often remove the intensity and severity of the static occlusions to get a clean point cloud model of the RC columns as shown in Figure 7.25 (*Process E)*.

As a result, the constructed 3D point cloud model encompasses all the details of the construction progress (the as-built).

To determine the construction progress status, the 4D BIM model is plugged-in to the AMAC system and synchronised with the computer's calendar to define the dates. And the 4D BIM model is able to recognise the as-planned construction progress at a certain date. For example, if today is the 3rd of December 2018, according to today's date and from the 4D BIM model, the construction progress is planned to be 100% for 10 number of columns (Column 1 through to Column 10). Thus, the 4D BIM model shows the 10 constructed columns in 3D view to allow a comparison against the 3D point cloud model for the same date. By doing this, it means the system compares the as-planned progress (4D BIM) against the actual progress (point cloud) for the same date to identify any the discrepancies (*Process F*).

In other terms, the constructed 3D point cloud model encompasses the details of the construction progress (the as-built) to detect the discrepancies between the as-built and as-planned schedule, which will be achieved by performing a comparison between the 3D point model and the BIM model (*Process F*).

In order to perform this comparison, algorithms 2 and ICP are employed to align and superimpose the 3D point cloud model onto the 3D BIM model for the columns as shown in Figure 7.25.

It is well known, that the 3D point cloud model consists of thousands or sometimes millions of points, and the coordinates for each point are expressed as(X, Y, Z). To synchronise these coordinates with the BIM model coordinates, the coordinates of the 4 cameras were precisely defined prior to capturing any image (during the calibration process), and accordingly the conversion algorithm was applied to synchronise the coordinates of the point cloud to the BIM model coordinates. The output of this process is *synchronised coordinates* of the two models.

It is worth mentioning that, this synchronisation process is done only once at the onset (during the calibration process). Wherein, the coordinates of 10 points were precisely defined; these points were largely the four corners and the centre of the building, in addition to five other randomly selected points on the building. Altogether they were considered the base/control points. And accordingly, the ICP algorithm and algorithm 2 was applied to align and superimpose the two models using the *synchronised coordinates*. This process was repeated 12 times and the best result was a displacement of 0.2 millimetre between the two models (BIM model and 3D point cloud model) which was phenomenal, as it did not affect the accuracy of the results, especially when the smallest dimension of the target objects is 400mm. Accordingly the margin error is 0.05% for the *smallest dimension*, which becomes less for bigger dimensions.

The output of this process is a perfectly superimposed point cloud model on the BIM model; Figure 7.25 illustrates the stages of superimposition of the two models.

Subsequently, algorithm 4 was applied to detect and calculate any discrepancies between the point cloud compared with the BIM model. If the result of the discrepancy this is negative sign showing that delays are detected.

However, if the result is positive this indicates that the progress is running ahead of the planned schedule, and if the result is zero, this shows that progress is in line with the construction plan. The output of this process is synchronised discrepancies with the as-planned schedule to demonstrate the progress status (*processes H and I*).

And subsequently, the output of (*processes H and I*) are exported automatically to Primavera P6 to calculate the percentage for each activity according to ID codes that were assigned at the outset of the project to each column as shown in Figure 7.27. The output of this process is the construction progress status for each column. Subsequently, if the progress status complies with the as-planned program, notification is not required. However, if the system detects any deviation between the as-built and the as-planned (*process J*), notification via SMS and email Figure 7.26 are sent automatically at 7:00 AM the next day to relevant staff (*process K*).

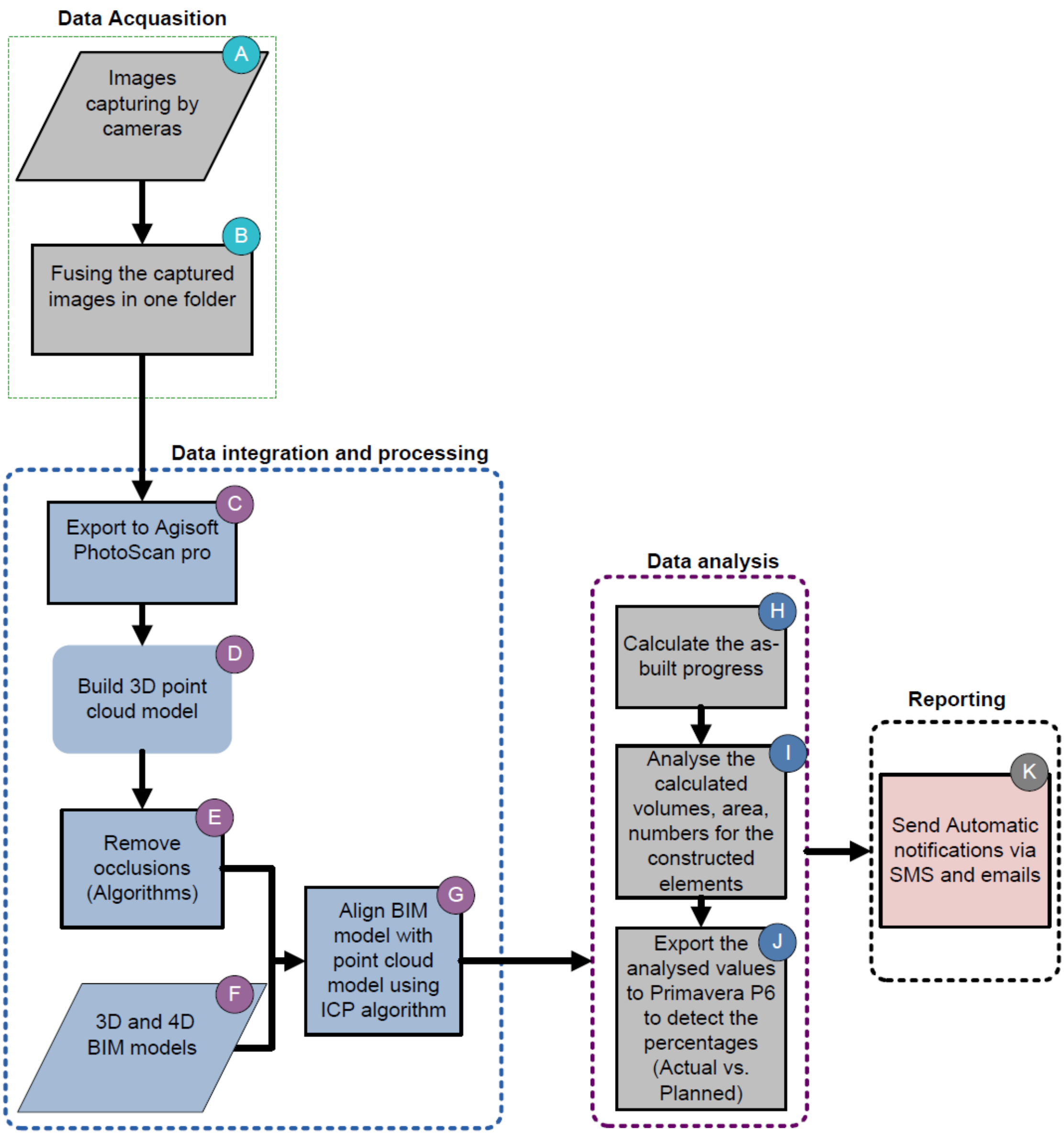


Figure **7. 23**: Developed model to automate monitoring and controlling construction site activities

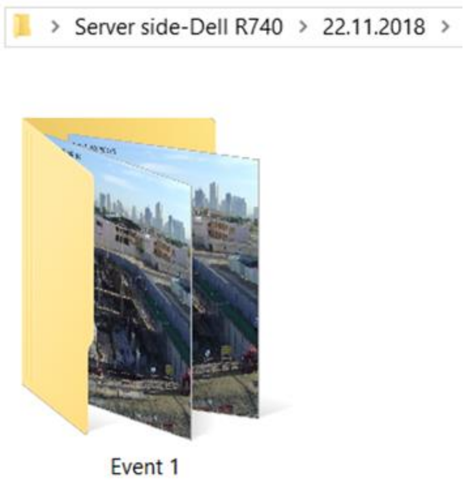


Figure 7.24: Screenshot for daily created folders

a) b) c)

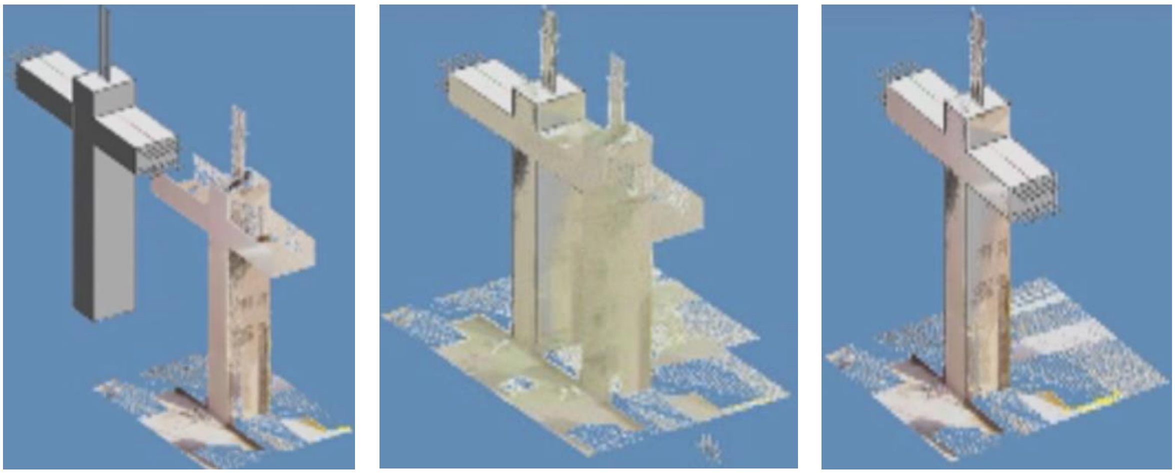


Figure 7.25: Stages of superimposing 3D point cloud model on 3D BIM model

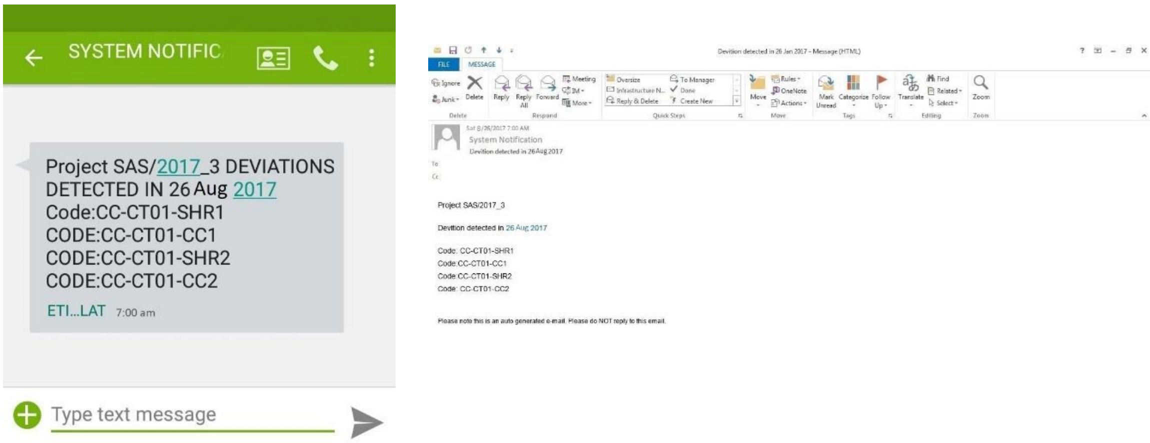
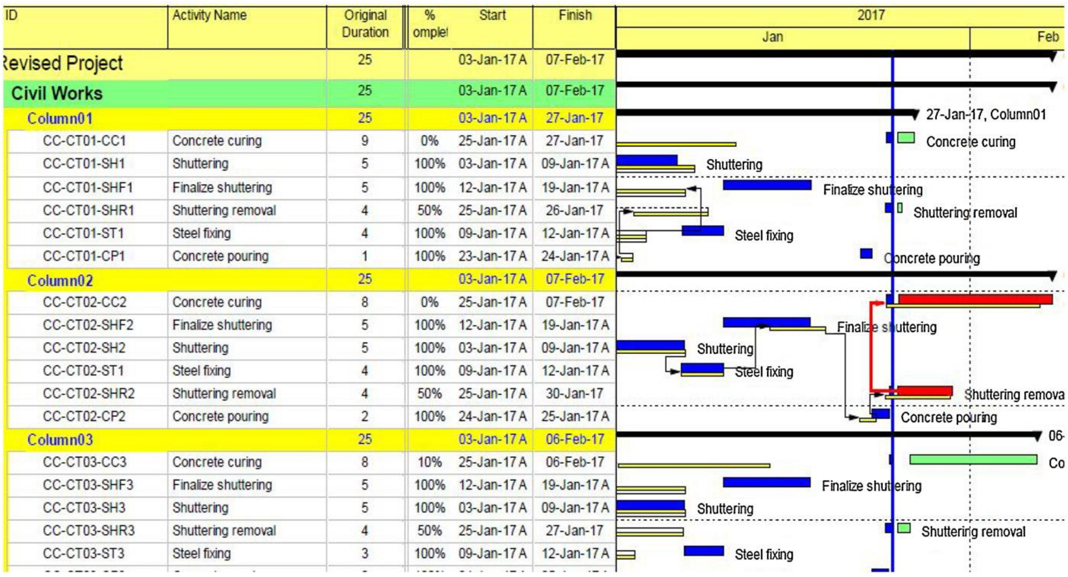


Figure 7.26: SMS and Email sent automatically to notify the project manager for the deviated activities detected by the system



ID	Activity Name	Original Duration	% omple	Start	Finish
evised Project		25		03-Jan-17 A	07-Feb-17
Civil Works		25		03-Jan-17 A	07-Feb-17
Column01		25		03-Jan-17 A	27-Jan-17
CC-CT01-CC1	Concrete curing	9	0%	25-Jan-17 A	27-Jan-17
CC-CT01-SH1	Shuttering	5	100%	03-Jan-17 A	09-Jan-17 A
CC-CT01-SHF1	Finalize shuttering	5	100%	12-Jan-17 A	19-Jan-17 A
CC-CT01-SHR1	Shuttering removal	4	50%	25-Jan-17 A	26-Jan-17
CC-CT01-ST1	Steel fixing	4	100%	09-Jan-17 A	12-Jan-17 A
CC-CT01-CP1	Concrete pouring	1	100%	23-Jan-17 A	24-Jan-17 A
Column02		25		03-Jan-17 A	07-Feb-17
CC-CT02-CC2	Concrete curing	8	0%	25-Jan-17 A	07-Feb-17
CC-CT02-SHF2	Finalize shuttering	5	100%	12-Jan-17 A	19-Jan-17 A
CC-CT02-SH2	Shuttering	5	100%	03-Jan-17 A	09-Jan-17 A
CC-CT02-ST1	Steel fixing	4	100%	09-Jan-17 A	12-Jan-17 A
CC-CT02-SHR2	Shuttering removal	4	50%	25-Jan-17 A	30-Jan-17
CC-CT02-CP2	Concrete pouring	2	100%	24-Jan-17 A	25-Jan-17 A
Column03		25		03-Jan-17 A	06-Feb-17
CC-CT03-CC3	Concrete curing	8	10%	25-Jan-17 A	06-Feb-17
CC-CT03-SHF3	Finalize shuttering	5	100%	12-Jan-17 A	19-Jan-17 A
CC-CT03-SH3	Shuttering	5	100%	03-Jan-17 A	09-Jan-17 A
CC-CT03-SHR3	Shuttering removal	4	50%	25-Jan-17 A	27-Jan-17
CC-CT03-ST3	Steel fixing	3	100%	09-Jan-17 A	12-Jan-17 A

Figure 7.27: Construction program for the project (the as-planned program)

7.2 Data analysis, results, findings and discussion for the development stage

7.2.1 Qualitative data inquiry- Face-to-face interviews

This stage of the research, that is the pilot project, involved face-to-face qualitative interviews with the users of the developed prototype. This is in accordance with the third and fourth processes of design science, which concerns "***development***" of the tentative design/prototype within a real-life case study and "***evaluation***" of the developed prototype with the users of the proposed prototype, respectively.

This stage of the research study involved system verification, which according to (IEEE STD-610., 2010, p. 394) is an iterative process of testing and evaluating the system during its development stage to ensure it meets the users' specified requirements.

To ensure successful development of the prototype, the following objectives were defined at the outset of the development stage for the pilot project:

1. Test, verify and evaluate the performance of the proposed prototype to prove the concept of the AMAC system.
2. Continuous refinements, amendments, and improvements to the prototype according to users' comments and feedback.
3. Develop a ready to use automated system (the final version) for detecting delays and timely sent automatic notification to support decision-makers.

The plan of this stage was proofing the concept for further generalisation and rolling out the system to include all construction elements such as foundations, beams, slabs, walls, etc., which will be validated in a full life-cycle case study in the next chapter.

According to Venable *et al.,* (2016) the users of any newly proposed system should evaluate and test its effectiveness which should be measured and evaluated against certain criteria. In this context, an extensive study of state-of-the-art systems for current monitoring and updating systems in addition to focus group recommendations has led to a profound understanding of the limitations faced and the benefits to be gained. This knowledge in addition to the recommendations made by participants of the focus group assisted in developing the following criteria for measuring the effectiveness of AMAC prototype. It was strongly recommended by Hair *et al.,* (2014), that researchers must develop criteria to measure success at each stage of the research.

Criteria for measuring the effectiveness of the proposed prototype:

1. The proposed prototype detects delays and sends timely automatic notification of such delays to support decision-makers.
2. The proposed system results in phenomenal savings in the project time and cost due to the ability of decision makers to take timely action in addressing delays.
3. The outputs of the proposed prototype are reliable and accurate.
4. The proposed prototype is easy to use, fully automated and does not rely on human intervention.

This stage sought to explore the users' experience to measure the effectiveness of the developed prototype and its benefits, and accordingly, face-to-face interviews via open-ended questionnaire were considered the best approach for data collection.

According to Saunders *et al.,* (2009) interviews are suitable for exploratory studies that seek to understand participants' experiences and observations to realise the relationship between different variables. Moreover, an open-ended questionnaire is a mix of closed and open-ended questions, which are usually used to explore the research topic according to the interviewees' experience (Tashakkori and Teddlie, 1998). Open-ended questions allow for more freedom, wherein, questions and their order allow for exploration and collection of more in-depth data from participants, that structured interviews preclude (Naoum, 2013).

7.2.2 Development of interview protocol

In order to enhance an understanding of the prototype's effectiveness, think-aloud protocol was adopted during the interviews. According to Fonteyn *et al.,* (1993) the think-aloud approach is about sharing one's thinking during a specific problem-solving task, which tends to provide a more complete narrative of one's reasoning for the solution. Several researchers have affirmed that the think-aloud protocol lures interviewees into expressing their insights openly and freely as it offers an informal environment. (Hinostroza *et al.,* 2018; Latif, 2019). Think-aloud protocol has been widely employed to analyse interviewees' responses within various research domains, such as education (Hamilton and Nussbaum, 1997; Hinostroza *et al.,* 2018), medical (Lundgrén-Laine and Salanterä, 2010), internet strategies (Cho, 2014), and construction project management (Kelley *et al*., 2014).

In order to evaluate and verify the effectiveness of the developed prototype, nine users who experienced and tested the prototype were interviewed using open-ended questions via face-to-face interviews. During these interviews, rather than strictly adhering to the pre-prepared questions, the researcher was flexible in approach reordering the questions and asking additional questions, in response to the interviewees' replies and interactions. This flexibility enabled greater freedom for the interviewees, who became more open and shared their thoughts and experiences freely, honestly and impartially.

The questionnaire consisted of seven questions Appendix 7, the first question asked the participants about their background. However, the remaining six questions explored the users' experience of the proposed prototype within three different areas as follows.

- ❖ The first area related to the users' evaluation of the effectiveness of the prototype for detecting and reporting the delays to support the decision makers to avert delays.
- ❖ The second is regarding the prototype's accuracy, reliability, ease of use and its capacity to save cost and time.
- ❖ The third comprised of users' suggestions to improve the performance of the prototype.

7.2.3 Selection of participants

Since the main task for the pilot project is testing and verifying the effectiveness of the developed prototype; the sample size for the face-to-face interviews included all users of the prototype. These nine users represented the management team who were involved in testing and verifying the prototype. The following Table 7.2 demonstrates the background of the nine interviewees.

Table 7.2: Participants of the face-to-face interviews

Participant code	**Specialty**	**Designation**	**Experience (Years)**	**Dubai experience (Years)**
IU	Owner	Project director	24	24
JA	Owner	Projects manager	21	14

AA	Owner	Project manager	23	11
IUR	Consultant-supervision staff	Resident engineer	27	15
NA	Consultant-supervision staff	Assistant resident engineer	16	9
OAI	Consultant-supervision staff	Senior inspector	20	13
AE	Contractor	Project manager	32	19
MV	Contractor	Deputy project manager	19	14
OA	Contractor	Construction manager	16	8
Average			**22**	**14**

The participants of the interviews were equally represented in the sample size i.e. 3 owners, 3 consultant's supervision staff, and 3 contractors. The sample size was equally selected to avoid bias towards any discipline.

As shown in the above table, the average of participants' experience is 22 years and the average work experience in Dubai is 14 years.

Involving relevant participants, with a robust in-depth knowledge of delays in construction was key as they have enriched the research with their insight from their experience, for the developed prototype, compared with their vast experience in the construction industry.

Indeed, the selected sample size was limited to the management team, largely as the project was still in its trial, testing and development stage. Furthermore, involving participants who do not have sufficient experience or are unable to communicate their experience can challenge and jeopardise the research due to ensuing due to misinformation (Kirkevold and Bergland, 2007). Furthermore, the interviewees were decision-makers; therefore, the successful implementation of the prototype system will create a greater buy-in tendency to adopt the final version of the system for any of their future projects. Furthermore, the selected interviewees have demonstrated practical experience in construction projects combined with robust in-depth knowledge of delays in construction which is the core theme of this research.

The users' shared meaningful information allowing for an in-depth comprehension of their experience, to recognise the strengths and weaknesses of the developed prototype for further refinements and improvements.

According to Dworkin (2012) there is no definitive number of sample size given for qualitative studies that entail in-depth interviews. However, the researcher should base their judgement of when the sample size is sufficient at the point when the data collection process no longer offers any new or relevant data, In this context, the nine interviews satisfied this condition which justifies the correct selection of the sample size (i.e. the nine interviewees).

Interviews were conducted individually over four days at the pilot project site. The shortest interview lasted for 35 minutes, whereas, the longest interview lasted for 52 minutes. This means the average time for the interviews was 43 minutes. Interviews were audio recorded after obtaining verbal consent from the interviewees; with the exception of one interviewee, an owner, who did not agree to the audio recording, and for which the responses were verbatim transcribed for further analysis.

7.2.4 Analysis of qualitative data

Details of how to analyse the qualitative data was introduced in chapter 5 section 5.4, thus, the same procedures were followed to analyse the interviews with the nine users of the proposed system. In light with the qualitative data analysis in chapter 5, the following processes were typically followed.

E. **Transcription of data:** the recorded interviews were scripted into texts in order to be fed into the NVivo software.
F. **Organisation of data**: scripted texts were organised to reduce its quantum and to correlate the responses to the research objectives to allow the categorisation of the emerging concepts.
G. **Categorising concepts and coding data:** this process entailed iterative reading of the scripted responses, which were categorised pursuant to the similarities in interviewees' concepts. To ensure reliability of the data analysis, this process was initially undertaken manually, and then repeated through using the NVivo software obtaining almost exacting results from both methods of analysis. This identical result conferred a confidence into the developed codes which were the basis for developing themes of the interviewees' responses.
H. **Theory/conclusion emerging from the developed themes**:
Development of themes involved the researcher's judgment to interlink and correlate the developed codes to the research objectives and questions. According to Creswell (2007), in order to avoid any bias during this judgement process, the researcher should refer to the research objectives. This process assisted the researcher to determine the effectiveness of the system based on the users' responses.

7.2.5 Findings of the interviews

The following word mapping shown in Figure 7.28 was the result of the analysis from NVivo 12 pro, which represent the most reiterated words, that emphasised concepts during the interviews. The word map assisted the researcher to develop the codes, and accordingly culminated the themes that interpreted the interviewees experiences and evaluation of the proposed prototype.

The developed codes are "***additional features***", "***dashboard required***", "***access to the system anytime from anywhere***", "***progress status for all activities***", ***and "3D viewer showing delays".***

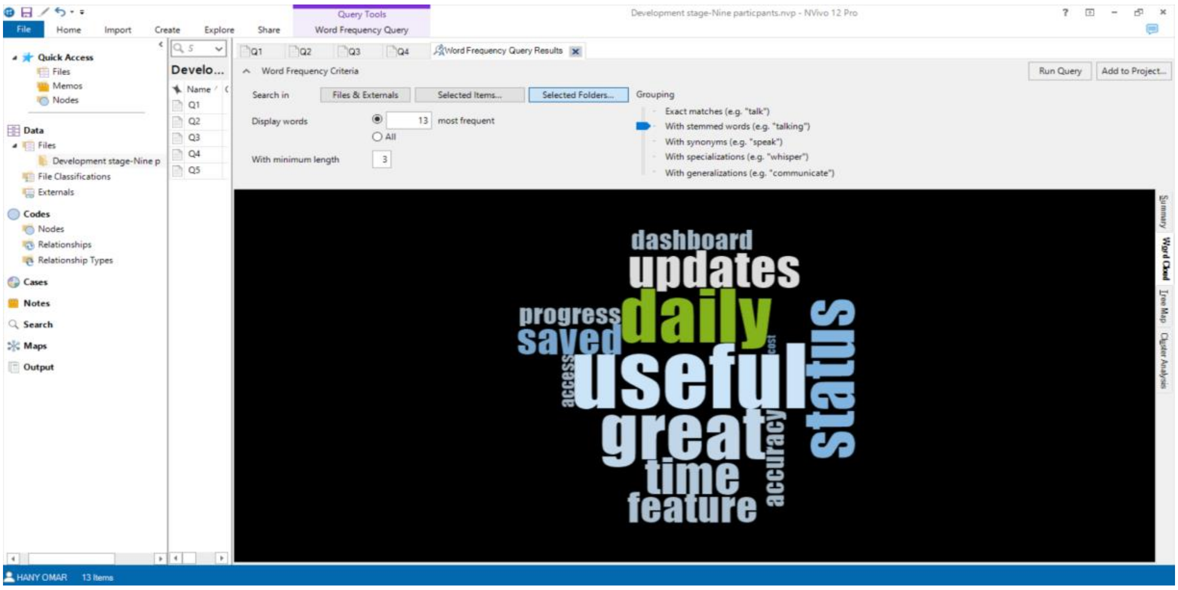


Figure 7.28: Screen shot for NVivo word map indicates keywords for codes

Based on the aforementioned codes, themes were structured as shown in Table 7.3 as follows.

Table 7.3: themes developed from the interviews

Theme	Sample of participants quotes (not all quotes are included)	Remarks
The system is innovative, but requires ***additional features***	• [NA] commented that this innovative system is long overdue • [AA] stated that the system is impressive with its daily	All the interviewees highly praised the system as an innovative solution for detecting and notifying the delays on a daily basis.

	notification of progress updates daily. However, the status for each activity is not included and to that end, he needed to refer back to the primavera to see the percentage of delays for each activity. The system should be comprehensive, which means the system should have additional features such as a 3D viewer to show the progress and illustrate the delayed activities in different colours. • [AE] commented that with some few additional features this system could be the eventual innovative solution to stop delays in construction projects [AE].	However, they highlighted that, the system requires further developments and improvements to include additional features.
3D viewer to show progress status for each activity	• [IU] expressed the missing function is a dashboard and additional features on the 3D viewer to show delays with each activity status being displayed. • [JA] stated the need to see the status for each activity even those not started yet, in addition to the delays with 3D view • [AE] disclosed that a 3D viewer that shows the in-progress activities, delayed activities and the status of all	The interviewees stressed the the urgent need to see the status for each activity whether started, in progress, delayed, ahead of schedule, etc. in a 3D view. The analysis of the progress status should include all activities to show the status of each activity independently.

	the activities would be an eminent feature • [OA] asserted the need to view the status of each activity in order to act accordingly	
***Dashboard** is required*	• [JA] affirmed that a dashboard would be a prominent and valuable addition to the system to show the progress status not only for the project overall, but also for delayed activities • [AA] claimed that a dashboard is critically required to figure out the status of all delayed activities • [OAI] stated that a dashboard to show the status of all the activities whether delayed or ahead of schedule is fundamental for such a system • [JA] The greatest weakness of the system is that there is no dashboard to show the status for all the affected activities. Moreover, according to the project status, the system should calculate the project overall expected completion date. • [MV] suggested that the system would be significantly better if there was a dashboard showing the status	There is a great deal of consensus among the higher level of management interviewees that a dashboard is a pivotal feature that must be added to the system. Some considered this is as the most significant weakness in the system. The dashboard should show the overall progress status for the project, in addition to the progress status of the affected activities.

	for all the impacted construction activities.	
Access to the system anytime from anywhere	• [IU] stated that the system should be accessible through web browser. • [JA] asserted that the system should be accessible at any time and from anywhere to allow observation of the progress status. • [AA] stated the need to access the system to check the delays and the project status. • [IUR] suggested that access to the system and cameras to monitor progress and safety would be a great asset of the system. • [NA] suggested that the ability to access the system to check at any time the status of all the activities and to access to cameras to know what activities are ongoing would be advantageous. • [MV] claimed that the system should be accessible anytime from anywhere.	Users highlighted that, as of now the system is sending them the overall project status showing the affected activities (i.e. the delayed activities), which is not enough for them to take decisions and further information is required. Users stated that they needed to have access to the system via a web browser to access the system from anywhere at any-time to check the status for all the construction activities. This suggestion was notably requested by the managerial and operational levels of whom tend to be detailed focussed.
The system is easy to use, accurate and reliable	• [JA] valued the system as easy to use and hassle-free which does not require more than half an hour training to operate it. • [AE, MV, and OA] declared that at the beginning they were suspicious about the	The system is easy to use, accurate and reliable.

	outputs of the system, which they meticulously checked several times against manual observations and surprisingly, the accuracy of the system often surpassed the accuracy of their surveying and inspection teams. The system is truly accurate and reliable.	

The following section discusses the findings of the qualitative interviews.

7.3 Discussion for the users' experience for the proposed prototype

7.3.1 Additional features are required for boosting the prototype performance

According to the data collection via face-to-face interviews, all the users of the prototype of the proposed system have appreciated the prototype's *ease of use, accuracy and reliability* which contributed significantly to saving costs and time in the project.

Accordingly, the predefined objectives for the pilot project, the stipulated criteria for measuring its success, and subsequently, the promising results of the proposed prototype which were appreciated by all the users; resulted in the proof of the concept for the proposed prototype be deemed as successfully accomplished. Indeed, all the users have praised the system as an innovative solution for detecting and notifying the delays in construction projects.

However, they have recommended inclusion of additional features to enhance the system's efficiency and capability. [AE] emphasised that by adding a few features to the proposed prototype would result in it being the long overdue innovative solution for stopping delays in construction projects and the main source of authentic data for decision makers.

Commonly, it is difficult to propose a system that is the answer to all users' requirements. Accordingly, it is common practice that the proposed prototype went through a series of improvements and developments. This course of action corresponds to the conclusions made by Markus *et al.,* (2002), that any constructed prototype based-software system must undergo a process of iterative identifications of its deficiencies to develop creative solutions in addressing these shortfalls.

Ultimately, the developed prototype has received much praise and appreciation from all the users of the pilot project. However, they have recommended additional features to be added such as dashboard, remote access to the system via web browser and additional features to the 3D viewer.

The following section discusses those features recommended by the users of the prototype.

7.3.2 Additional features to the 3D viewer to show progress status for each activity

Realising the progress status for each activity was the collective demand from all the interviewees, especially from within the managerial and the operational levels. [MV] stated it was a necessity to know the status for any activity, such as the following: when did it start or will it start, when it finished or will finish, has this activity incurred any delays and how long is the delay. [MV] asserted the need for only one legitimate system to refer to the program of works and be informed of the status for any activity.

According to the literature study, the 3D viewer has been widely used as an integral part of several initiatives to show the progress status such as the systems proposed by (Dawood *et al.,* 2002; Chau *et al.,* 2004; Ibrahim *et al.,* 2009; Roh *et al*., 2011; Zhiyang *et al.,* 2019). Conversely, other researchers have included only the bar chart to indicate the status for the activities such as (Abeid *et al.,* 2003; Behnam *et al.,* 2016; Braun and Borrmann, 2019).

However, the literature shows that current systems, to seek to detect delays and update the progress of a construction project, lack the ability to incorporate both features. And thus, after adding both features to the refined prototype, this makes AMAC system far superior current and previous systems.

Indeed, the novelty of introducing the 4D viewer to show all aspects of the progress status for each construction activity as shown in Figure 7.29 is the first of its kind. In other words, the 4D viewer is a unique feature showing not only the deviated activity, also progress status for all project activities.

Figure 7.29: Screen shot for AMAC 4D viewers showing the progress status for each activity

As shown in the zoomed-in Figure 7.30, the 4D view feature allows the users to recognise the status for any construction activity. For example, the user can press on the "***current day***" button shown in the figure below, to recognise what the activities are running on the "***Current day***", and if the user wants to know what are the *late activities* they can click on "***Late***" button. Additionally, where users want to know what the *completed activities* are, they can click on "***Finished***", and similarly the activities "***in progress***". Furthermore, the status of all the project activities can be displayed when ***"All"*** is clicked on.

The below screenshot shows the status of "***All***" activities which elaborates as to why some activities such as "***Const-1010***", "***Const-1100***" and "***Const-1130***" have a progress status as 0%. This is due to the start date for those activities being in the future at that time (i.e. 26 December 2018 and 7 January 2019 respectively). It is evident from the progress status on the screen below, that it was 'screenshot' before 26th December 2018.

However, activities such as "**Const-1040**" and "**Const-1050**" are in progress and their progress status is 35%, and delays were not shown, mainly because these activities did not suffer from delays as their late finish date did not elapse yet.

The planned starting date for this "**Const-1040**" was 25 December 2018, however, it started five days earlier on 20 December 2018 as shown in the screenshot below, which shows a progress of 35% with no delays incurred, as the 'Late Finish' date did not elapse at the time of checking which is obviously on 25th December 2018. Likewise, for the activity "**Const-1050**".

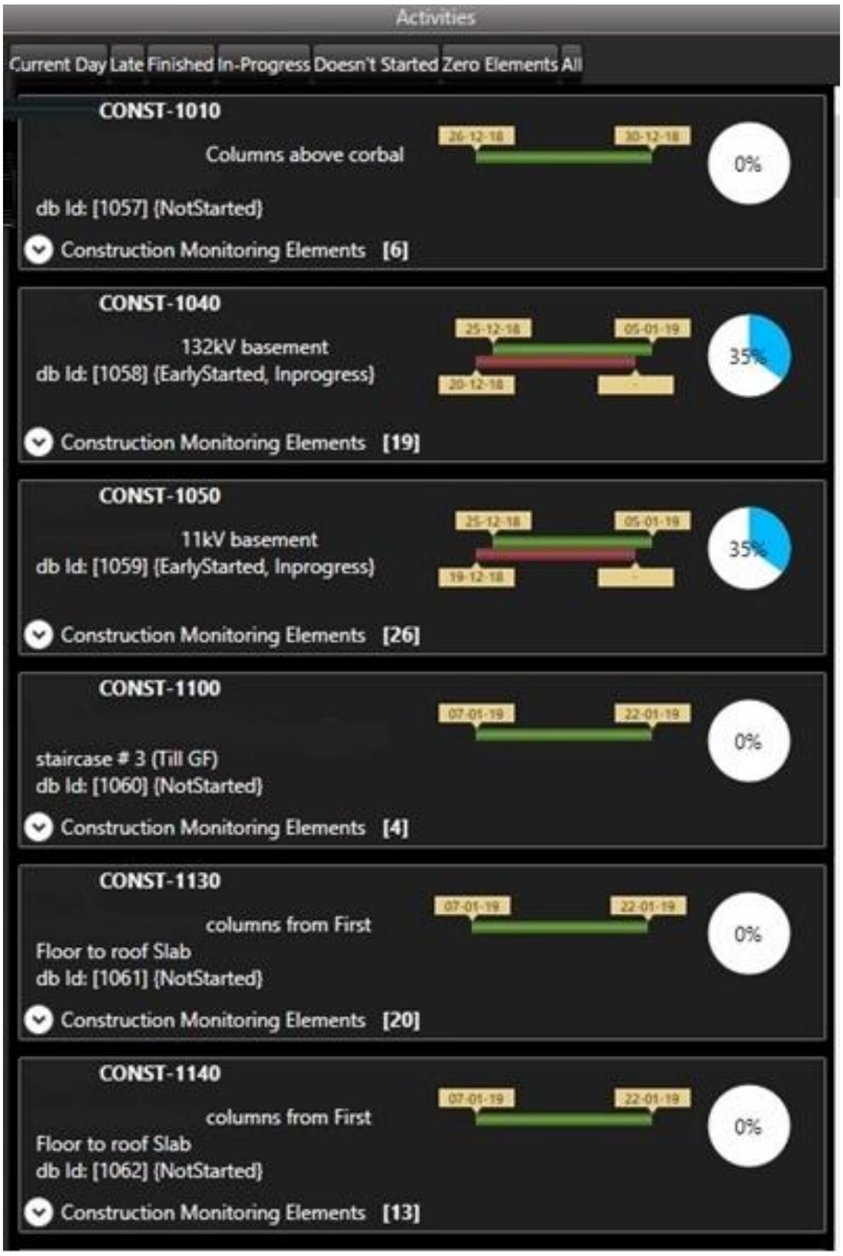


Figure 7.30: Zoomed-in screenshot for the 4D viewer

The design of this feature underwent several iterative refinements and developments. All these developments were presented to the nine users, during the pilot project and after three and half months of developments. The 4D viewer was completed and tested in the pilot project which was appreciated and accepted by all the users.

7.3.3 Dashboard

All users, specifically the senior management have stressed the critical need to have a dashboard as part of the system; with the main function of the dashboard to summarise the overall progress status for the project. Moreover, the dashboard will be required to illustrate the progress status and the affected activities in a way that is easy to use and understand, by showing the planned progress against the actual and the variances.

Few (2006, p.34) defined a dashboard as "*a visual display of the most important information needed to achieve one or more objectives, consolidated and arranged on a single screen so the information can be monitored at a glance*".

Indeed, a dashboard is seen as the mainstay tool that augments transparency and clarifies accountability in construction projects, and in particular for the pertinent issue concerning delays. Matheus *et al.,* (2018) considered the dashboard as an important means of communication and interaction amongst teams, which accordingly improves transparency and accountability as each party understands the necessary action that should be taken. In this context, Maheshwari and Janssen (2014) affirmed that the dashboard supports decision makers, for prompt action.

The literature study revealed that some of the current systems have developed a dashboard as a feature to comprehensively summarise the construction progress status, such as (Abeid *et al.,* 2003; Kam and Fischer, 2004; Song *et al.,* 2005; Sun *et al.,* 2015; Matheus *et al.,* 2018; and Braun and Borrmann, 2019).

In line with the abovementioned directives, the design of AMAC dashboard was comprehensive, simple, easy to use and understand. After a three- and half-month development process the 4D viewer was completed and tested within the pilot project as shown in Figure 7.31 and was welcomed and valued by all nine users and responded directly to their requirements.

The dashboard was not tested in the pilot project, mainly because it is intrinsically linked with and dependent on the 4D viewer and accordingly, development of the dashboard came after the development of the 4D viewer. The 4D viewer entailed three and half months of developments to perfectly address all the comments received from the users, in addition to a two week trial, which makes the total duration of four months to fully develop the 4D viewer.

Additionally, development of the dashboard started in the fifth month of the pilot project which required six weeks for development, this makes the overall duration for developing the dashboard more than six months.

However, the pilot project duration was only six months, and therefore, only a mock-up of the dashboard was introduced to the users who found it acceptable. Accordingly, the dashboard will be a part of the system in a full-cycle project which will be introduced in the next chapter.

It is important to underline that the dashboard shows only the deviated activities compared against the as-planned program, that is, the delayed tasks.

However, the 4D viewer shows the status for all construction activities, regardless of its status, which means it displays the deviated and non-deviated activities.

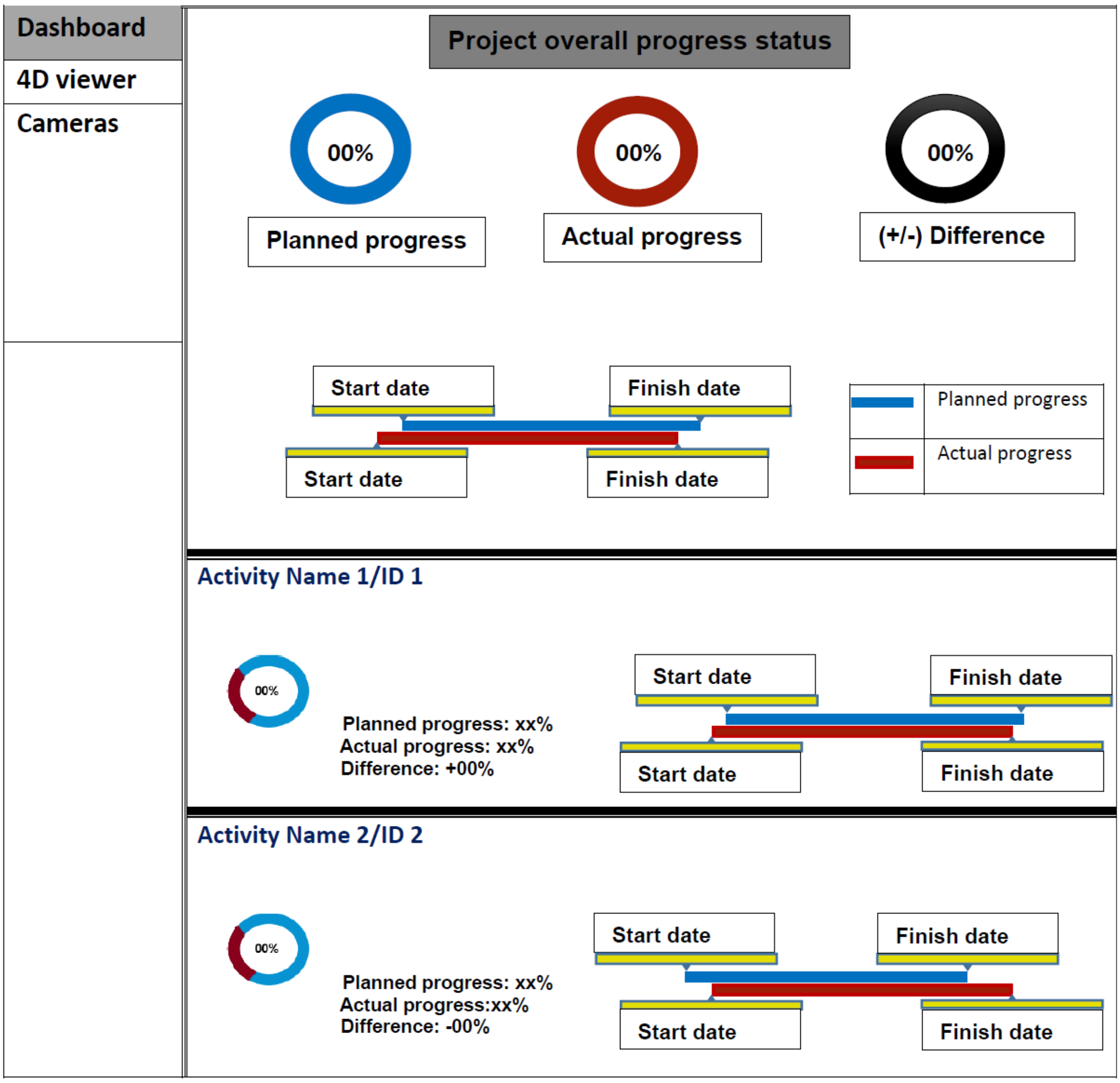


Figure 7.31: The approved design of the required dashboard

7.3.4 Access to the system anytime from anywhere

All users requested access to the system to determine the progress status for all activities, in addition to, the overall project status, and to know what activities are delayed as this information often needed during progress meetings. They also suggested the ability to access the system from anywhere at any time, not just from the site offices or at the clients' premises.

Although, the initial design of the system did not include monitoring the cameras to check the contractor's adherence to the site safety measures or remote inspection of the construction progress; the PTZ properties of the cameras, were exploited for that use and considered as an additional benefit of the system.

Pursuant to the users' request, they were granted access to the "***cameras***" as shown in Figure 7.32. They were able to access and control any of the four cameras including Pan, Tilt and Zoom on any view of the camera to monitor any potential site safety issues. Additionally, they were able to visualise the ongoing and completed activities without travelling to the site.

Figure 7.32: Full control and access to the cameras

Responsibility for the ongoing administration of the system such as granting access to users or withdraw access for existing users was a sensitive and critical role and as such the researcher was the sole administrator of the system with full control. Permitting access to users is initiated by the researcher sending a "*setup.exe*" file via email to be installed on the user's machine as shown in Figure 7. 33.

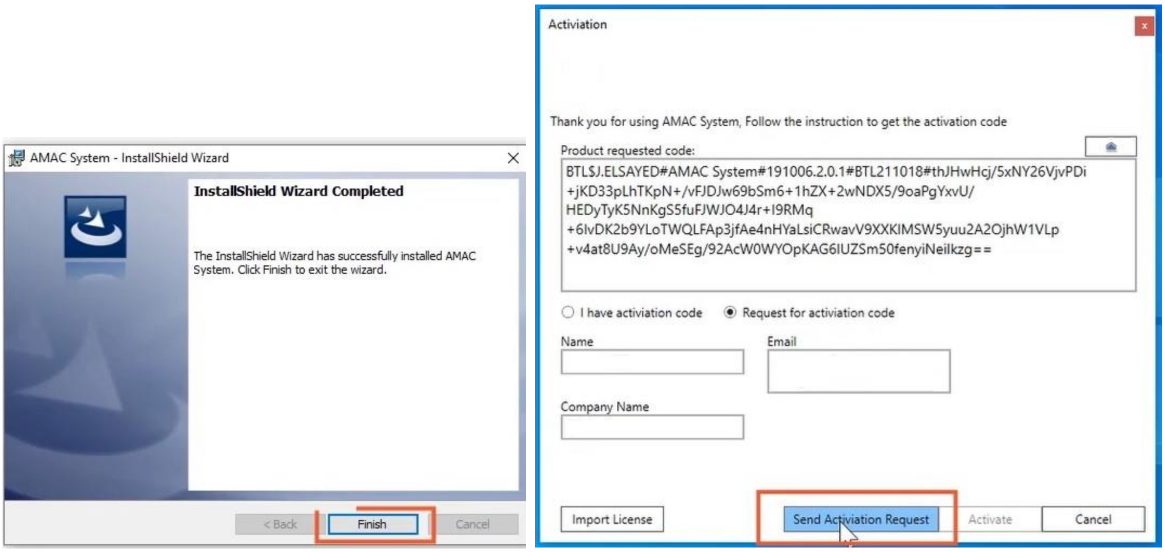


Figure 7. 33: Installation and activation of AMAC system on users' computers

Once the installation completed, users need to request an "activation code" to ensure only authorised users can access the system. The administrator then forwards the activation code via email to the user, and once their user profile is activated, a shortcut is automatically created on the user's desktop. Therefore, users are able to access the system from anywhere at any time through any web browser.

Accordingly, it takes only a few seconds to access the system and users can navigate any of the available features, for example if the user wants to realise the project's overall progress and any deviated activities, they will need to access the "**Dashboard**". However, if the user wants to know the status of a specific activity, they should access the "**4D viewer**". And in the case that the user wants to remotely inspect the ongoing or completed activities in a live stream or wants to check the contractor's adherence to safety measures without travelling to the site, they should access "**Cameras**".

7.3.5 The prototype's ease of use, accuracy and reliability

The users have valued the prototype's ease of use, whereby, some mentioned that the system does not require any special training to learn how to use it, whilst others suggested that only 30 minutes are required to become a proficient user of the system. All in all, the feedback was that the system is hassle-free and simple to use.

The accuracy and reliability of the information developed by the prototype was held in high esteem by all of the users. The contractors expressed scepticism at the beginning of the project, about the quality of the information provided by the prototype; whereas, they tended to experience multiple discrepancies between the automated information developed by

AMAC system and information acquired from their surveying, inspection teams and planners.

As such, the PM meticulously checked the prototype system's accuracy against the data collected and analysed by his best team. The task of acquiring exacting details manually and the careful analysis of these details and reporting the progress status was repeated at different times on different days.

The results were surprising to the contractors, whereby, the prototype outputs were more accurate and reliable than those of their best surveying team. The team of contractors stated that the prototype system was more accurate and reliable than their best team who tend to spend several days, in acquiring, analysing and reporting the data which was done by the system on a daily basis and at with no ongoing costs. Accordingly, the system would save time and associated costs of the surveyors, inspection and planning teams. Moreover, the decisions can be made based on quality information and in a timely manner to alleviate or prevent delays.

7.4 Summary for this Chapter

The pilot project offered a practical experience for testing, evaluating and verifying the prototype within a real-life case study. Interviews conducted with the users of the prototype resulted in the proposal of additional features on the 4D viewer which is an original characteristic that enabled users to determine the progress status for any construction activity.

Moreover, users proposed the addition of a dashboard feature to recognise the overall progress of the project showing only the affected/deviated activities compared with the as-planned program.

The ability to access the system from anywhere at any time to monitor the ongoing or completed activities in a live stream was a valued feature too.

All these features were developed and tested in the pilot project with the exception of the dashboard which will be tested in a later case study, largely due to its development taking more time that was allowed for in the pilot project.

Accordingly, after addressing the comments and recommendations from the feedback; it became necessary to validate the system within an additional case study with a set of different users, to aggregate any additional and different suggestions and insights about the system from the start of the project until its finish.

Validation of the system will be introduced hereinafter in the next Chapter.

Chapter 8- Testing and validation of the proposed system- Development stage-II

8.0 Introduction

The main objective of this Chapter is testing and validating the effectiveness of the developed system in a subsequent development stage with a group of users via an online survey, in a real-life case study project in Dubai. This group is made up of 40 users' representative from the management and operational teams of the case study (i.e. 10 contractors, 10 sub-contractors, 10 consultants and 10 from the project owner).

This Chapter is divided into three sections. The first section demonstrates the features of AMAC system that were tested and validated by the 40 users in the full lifecycle case study project.

The second section introduces the empirical validation which involved data collection via online survey for the 40 users reflecting their experience of using AMAC system. The collected data was statistically analysed using the Mann-Whitney *U* test to recognise the users' level of satisfaction and the effectiveness of the AMAC system compared with the conventional approach. Additionally, to ensure reliability and validity of the AMAC system, the performance track record for the past 10 years for projects similar to the case study were reviewed thoroughly for the purpose of longitudinal comparison between the effectiveness of AMAC system and the conventional approach.

Lastly, the external validation introduced, wherein, the accuracy of AMAC system was statistically scrutinised and compared with similar systems developed and published by other researchers to ensure robust confidence in the AMAC system within the construction industry.

8.1 Development stage-II, Full cycle project- Case study

The developed prototype demonstrated promising results which were acknowledged by the users of the pilot project who tested and evaluated the system. Accordingly, their feedback and comments were addressed during the development stage refining the final version of AMAC system which was planned to be validated in a comprehensive full lifecycle project.

This approach corresponds with Martins *et al.,* (2015), of whom tested the prototype in a pilot project with a small number of participants from the general population and the data collected in the pilot project was used to refine the prototype for the development of the final version of the system. In the same context, Crawford *et al*., (2009) emphasised the importance of testing and validating any developed software system to check its performance and capabilities.

Clearly, this could only be achieved by rolling out the system in a full lifecycle case study from start to finish to validate the effectiveness of the system in comparison to other approaches.

According to design science, the third process is “***Evaluation***” and this should be conducted only once. However, to ensure exacting outputs for the proposed system the researcher sought to retest, re-evaluate and validate AMAC system as a final development version ready to use in the context of a real-life construction site in Dubai.

To select a suitable project, various sites were visited and evaluated according to the criteria below, and 32/11KV electrical substation was selected to be the first project for the roll out of the final version of the AMAC system.

8.1.1 Criteria for selecting the rolling out case study

1. The case study was selected to be in its early stages where construction activities had not yet started.
2. The contractor should be cooperative and supportive of innovation and change and should be willing to share all details of the project.
3. All drawings are available as a 3D BIM model.
4. The site is accessible at any time i.e. 24/7.
5. Full permission to use the contractor’s facilities such as internet, offices, and dedicated staff as needed.
6. The location of the site also was selected carefully to allow flexible and easy fixing of the cameras without disturbing the ongoing operations.
7. Installation of cameras and the hardware starts concurrently at the time of site mobilisations prior to commencing any construction activity.

8.1.2 Case study- brief description

The selected case study project was the 132/11Kv electrical substation owned by DEWA. The selected project/case study was constructed in Dubai, United Arab Emirates, the project location map and project signboard are shown Figure 8.1 and Figure 8.2

respectively. Whereas, the red flag in Figure 8.1 pinpoints the location of the project case study on the Google map. A brief overview of the project can be found below:

Project Name: Design, Supply, Installation, Testing and Commissioning of 132/11kV substation and its associated works. A 3D model of the substation is shown in Figure 8.2, Figure 8.2, Figure 8.4 and Figure 8.4, in fact, this substation is identical to the pilot project substation.

Contract type: Design and Build (D&B)

Contract value: AED 72,589,850 ≈ (£ 15,122,885)

Contract start date: 21st December 2017 **Contract completion date:** 19th January 2020

The owner: Dubai Electricity and Water Authority (DEWA)

As mentioned in chapter 7, DEWA has one typical model for its 132/11 Kv substations. The details of this case study replicate the details of the pilot project that can be found in section 7.1.3, and the typical model of the case study is shown in Figure 7. 1 and Figure 7.2 via chapter 7.

As per the condition of the contract, the main contractor is responsible for updating the construction plan, to show the progress status and submit it to DEWA as an integral part of weekly progress reporting.

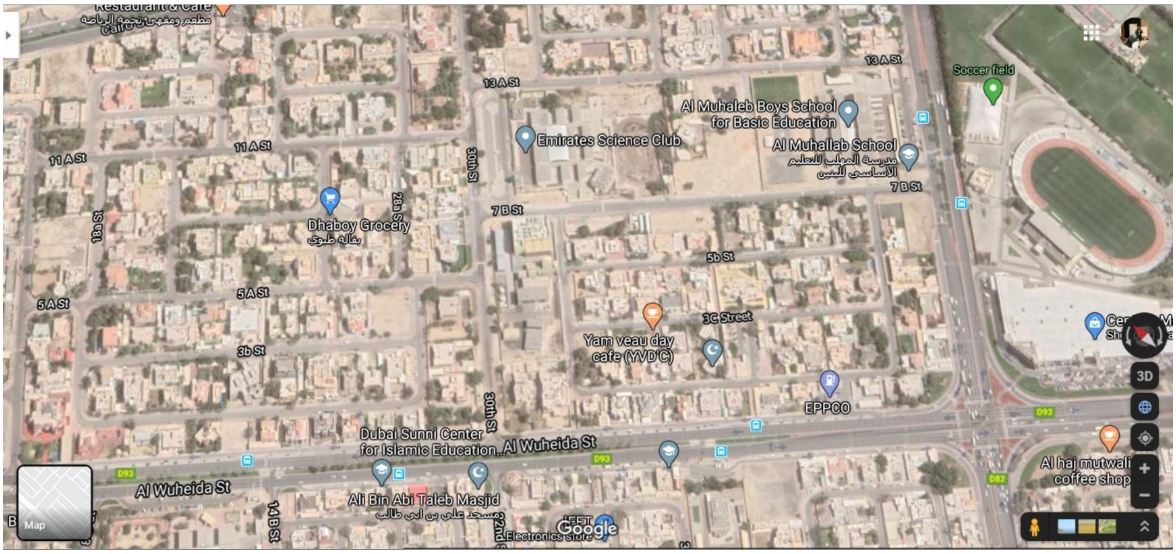


Figure 8.1: Location map for the case study

Figure 8.2: Case study sign board

Figure 8.3: case study BIM model, main entrance

Figure 8.4: Substation back side view

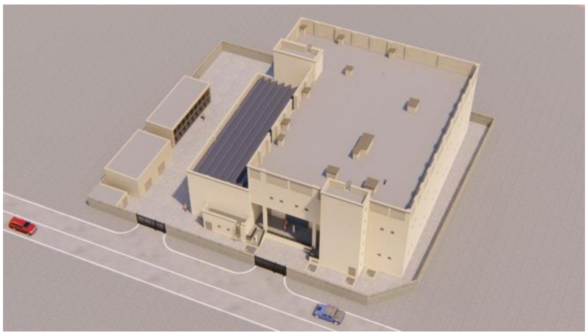


Figure 8.5: Substation main entrance view

8.1.3 Final version of AMAC system

The promising and successful achievements from the pilot project paved the way for rolling out the final version of this system in a real-life case study. The aim of this case study is to validate and rigorously test the performance of the final version of AMAC system in a real-life case study (i.e. the Substation).

To that end, cameras were installed following the same approach as the pilot project for camera installation (Chapter 7), except for the tower crane camera, as this project had no tower crane.

The cameras were designed to capture photo stills not only for RC columns as in the pilot project, but for all the civil works such as RC elements (foundations, raft foundation, beams, slabs, walls, columns, brickworks, etc.). These structural elements were selected, mainly because they are the main elements of any civil works, which often lay on the critical path and accordingly, any delay(s) for the civil works are likely to affect the project adversely, thus leading to overruns.

However, mechanical and electrical works, equipment, finishing works such as painting, and fit out works were outside the scope of this study.

The design of terrestrial data capture entailed fixing twelve cameras to cover the whole site; these cameras were installed and programmed to capture photos in two events (i.e. capturing times). The first event starts capturing photos one hour after sunrise and the second event takes place one hour before sunset; the capturing times of the two events are not fixed as it varies according to season.

In fact, these two times were carefully selected based on the practical experience gained in the pilot project, mainly to allow for a sufficient number of images, to reduce the glare caused by the sunlight and to reduce the dynamic occlusions caused by the movements of machines, equipment and labours. Accordingly, these two events were deemed the best times to capture photos due to the lighting and glaring issues. In addition, it best captures the progress as a cut-off time every day, whilst allowing the system to compute the progress overnight, ready to send the notification email and SMS the next morning; to support decision makers in taking the appropriate actions based on the updated progress status.

Automating and programming the cameras follows the same process used during the pilot study outlined in Chapter 7 section 7.1.5 and 7.1.6.

The used hardware and software is also the same that was used in the pilot project and is summarised in Table 7. 1; however, the number of the used cameras were twelve instead of the five used in the pilot project. The design of the cameras and installation methods and positions are detailed hereinafter.

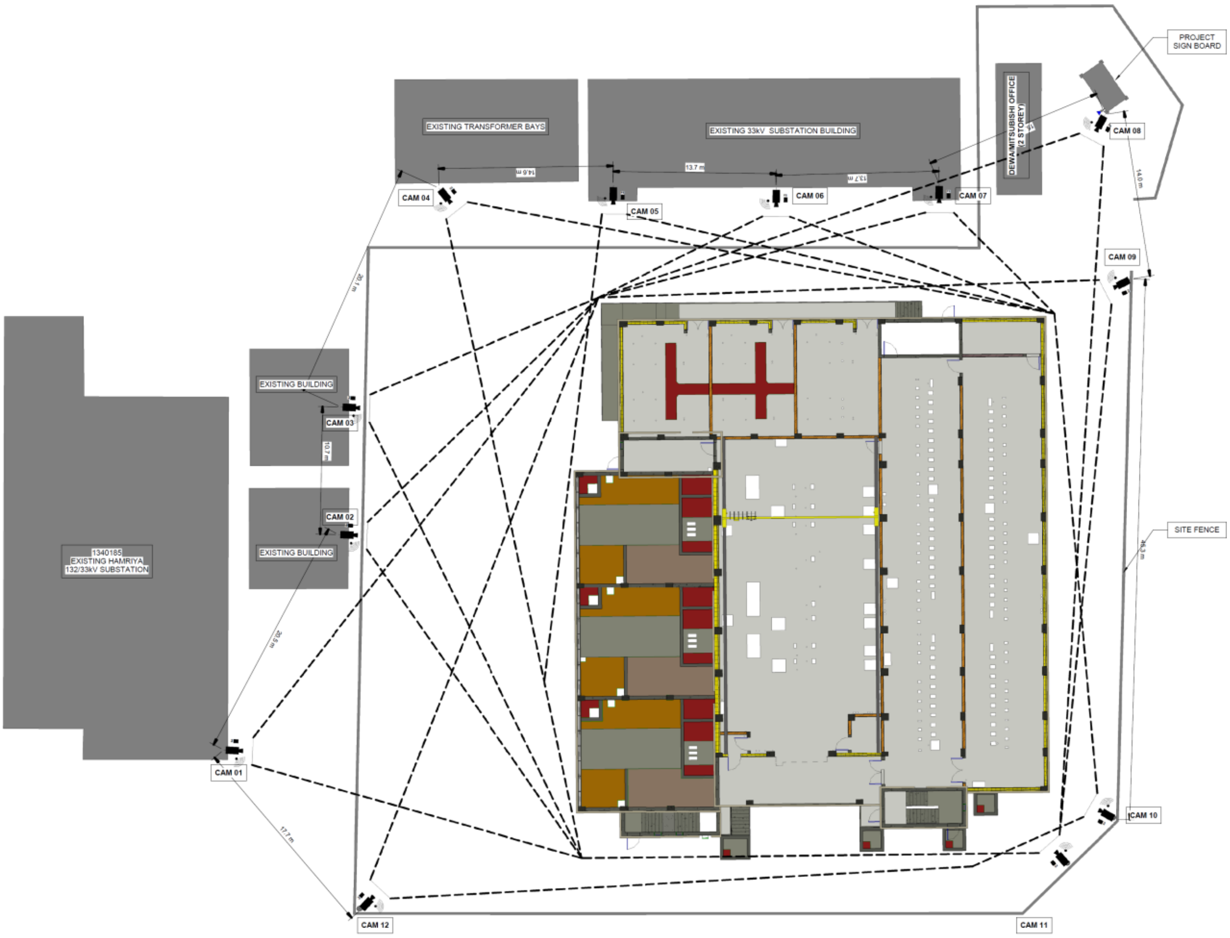
8.1.4 Camera installation

The design of Terrestrial Data Capture System (TDCS) demonstrated in Figure 8.7 shows the locations of each camera. The interactive Excel sheet for TDCS/distance calculator is included in (Appendix 5) which determines the maximum distance from the camera to the object as 43.00 m.

According to the site conditions, there were two methods for camera installation:

- As shown in Figure 8.6, cameras were installed on the existing four buildings and the project signboard adjacent to the project case study site, as shown in cross sections 2, 3, 6, 7 and 8 via Figure 8.8.
- However, the designated locations whereby there is no existing building; cameras were fixed onto a freestanding mast designed in the same way as the pilot project. Figure 8.8 sections 4 and 5 show the freestanding masts.

Figure 8.6: Existing buildings close to the construction site



CAMERA	BRACKET TYPE	HOSTING TYPE	NOTES
CAM 01	GOOSENECK MOUNT	EXISTING BUILDING - WALL	1. THE CAMERAS HEIGHT SHALL BE AT THE HEIGHTEST POINT AS MUCH AS SITE CONDITIONS ALLOW 2. THE CAMERA POSITION MAY BE VARIES IN THE HORIZONTAL PLAN (+ OR - 300 MM) DEPENDS ON THE SITE CONDITIONS 3. FOLLOW THE CAMERA'S MANUFACTURE INSTALLATION GUIDE 4. MOUNTING STELL BEAM HEIGHT FROM 6~8 METERS
CAM 02	WALL MOUNTED BRACKET	EXISTING BUILDING - WALL	
CAM 03	WALL MOUNTED BRACKET	EXISTING BUILDING - WALL	
CAM 04	WALL MOUNTED BRACKET	EXISTING BUILDING - WALL	
CAM 05	WALL MOUNTED BRACKET	EXISTING BUILDING - WALL	
CAM 06	WALL MOUNTED BRACKET	EXISTING BUILDING - WALL	
CAM 07	WALL MOUNTED BRACKET	EXISTING BUILDING - WALL	
CAM 08	VERTICAL POLE MOUNTING BRACKET	PROJECT SIGN BEAM - BEAM	
CAM 09	WALL MOUNTED BRACKET	STEEL BEAM 6 ~ 8 METER HEIGHT	
CAM 10	WALL MOUNTED BRACKET	STEEL BEAM 6 ~ 8 METER HEIGHT	
CAM 11	WALL MOUNTED BRACKET	STEEL BEAM 6 ~ 8 METER HEIGHT	
CAM 12	WALL MOUNTED BRACKET	STEEL BEAM 6 ~ 8 METER HEIGHT	

Figure 8.7: Camera positions with FOV, (dotted lines are FOV)

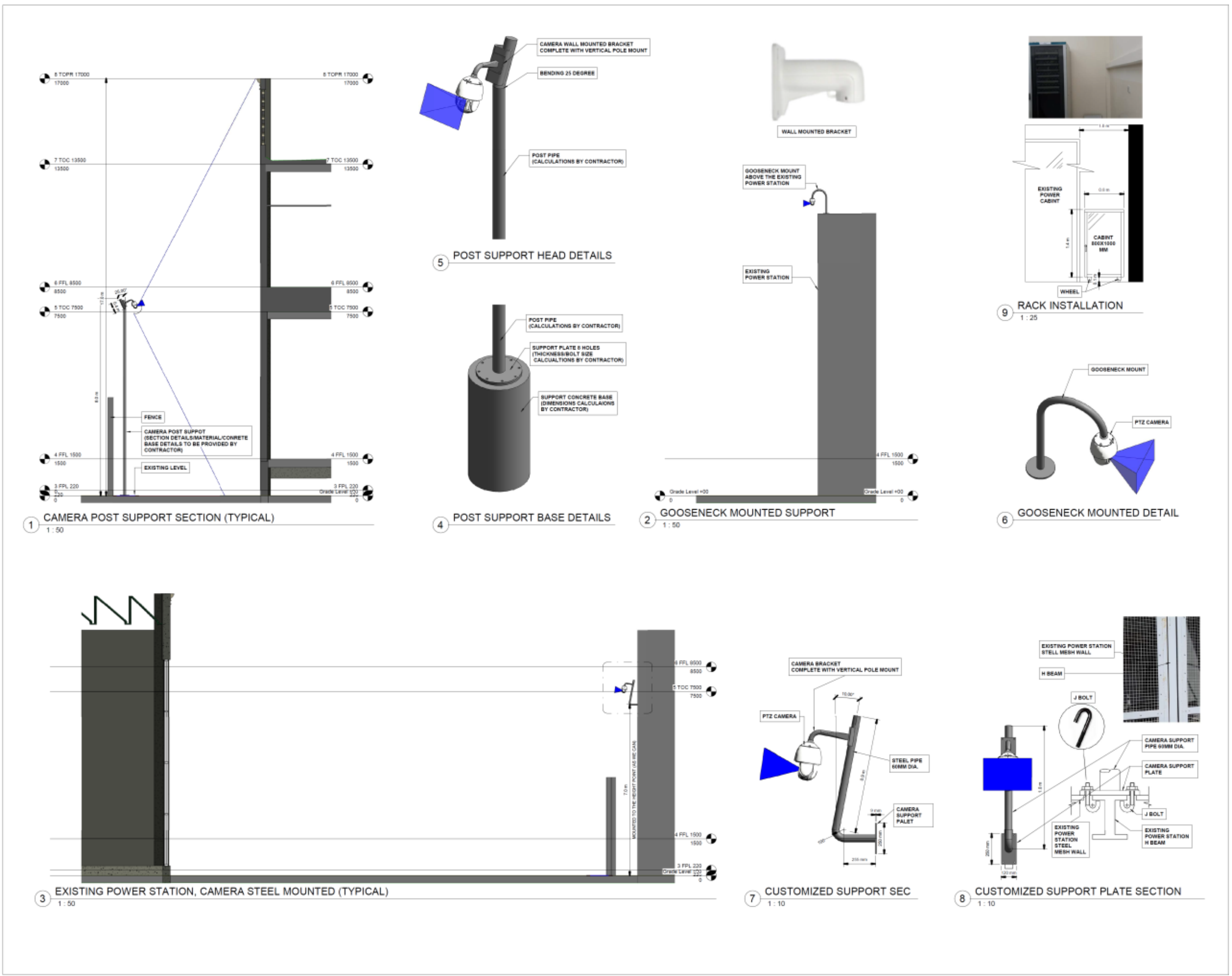


Figure 8.8: Cameras installation methods

The installed 12 cameras with its given numbers are illustrated in the following Figure 8.9. As shown cameras 1, 2, 3, 4, 5, 6 and 7 were installed on the buildings adjacent to the case study. Camera 8 was installed on the project's signboard and cameras 9, 10, 11 and 12 were installed on the freestanding masts.

Camera 1

Camera 2

Camera 3

Camera 4

Camera 5

Camera 6

Camera 7

Camera 8

Camera 9

Cameras 10 and 11


Camera 12

Figure 8.9: The installed 12 cameras

The method statement for camera installations including the used equipment and manpower in addition to the risk assessment and safety measures are included in Appendix 8.

According to the site condition cameras 10 and 11 were designed to be close to each other, to allow a manoeuvring room for the crane for handling the materials as shown in Figure 8.10. Due to site restrictions the installation of tower crane was not allowed.

Consequently, the maximum clear distance was maintained between cameras 9 and 10 for crane manoeuvring, similarly, the maximum clear distance was maintained between cameras 11 and 12 in the other side as shown below.

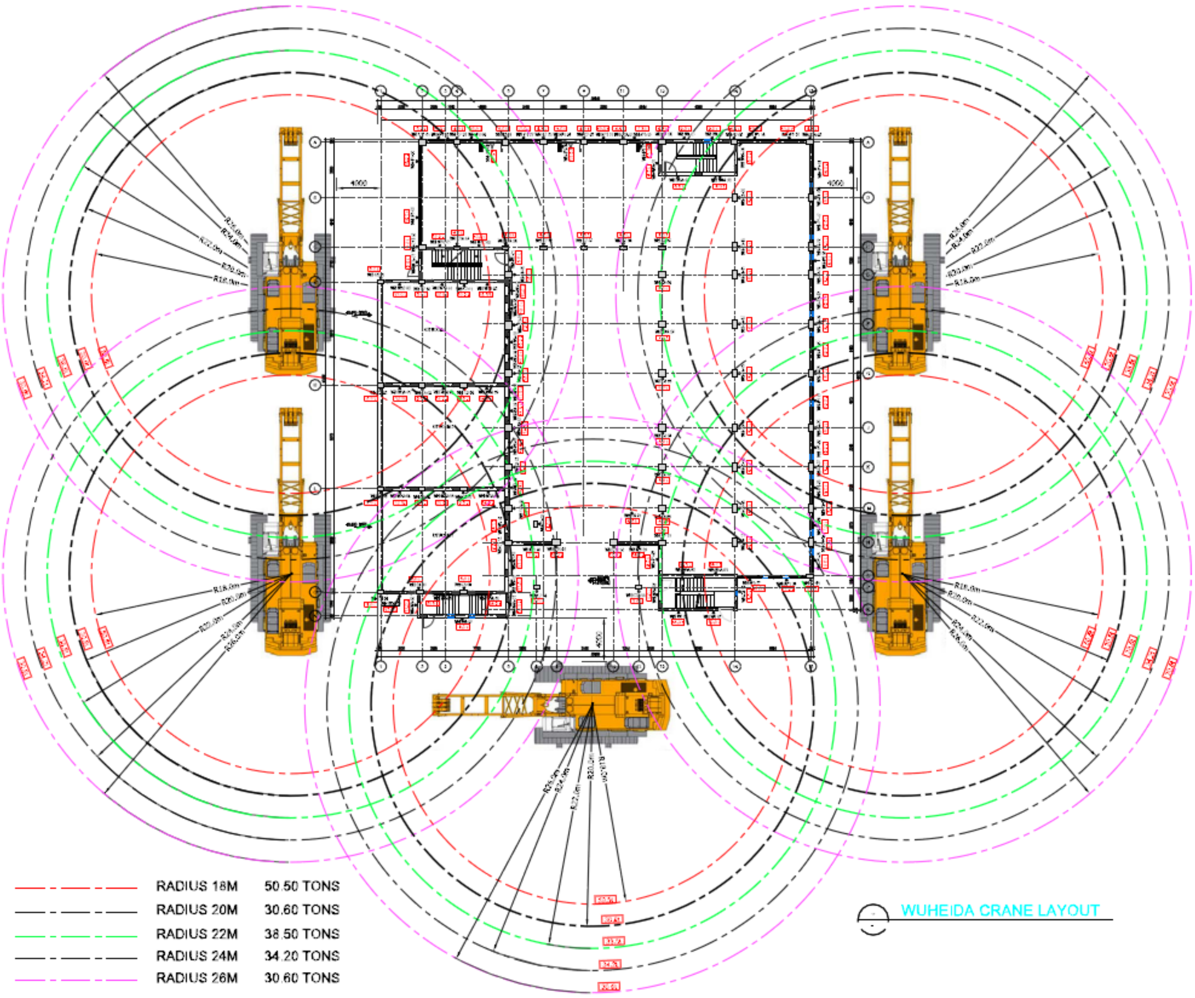


Figure 8.10: Crane lifting and manoeuvring plan

Acquiring optimum clarity of detail for the captured images entailed calibrating camera's intrinsic and extrinsic parameters prior to installing the cameras in their designated positions.

8.1.5 Camera calibration

Calibration of the twelve cameras and removal of occlusions followed the same method and sequences as outlined in Chapter 7 sections 7.1.6, through 7.1.9.

8.1.6 AMAC system functionality and processing

Cameras were programmed to turn on automatically to start capturing photo stills according to each camera's pre-set, wherein the movement for capturing photos was for every 3^o horizontally and 5^o vertically (functionality of horizontal and vertical capturing were explained in Chapter 7 section 7.1.5).

The number of captured images for each event was 306 images, thus, the total number for the two events were 612 images. And the overall duration required to capture these photos for one event was 24 minutes (which was 2 hours in the pilot project).

Figure 8.11 illustrates screenshot that depicts the number of images and the duration for capturing these images for one event.

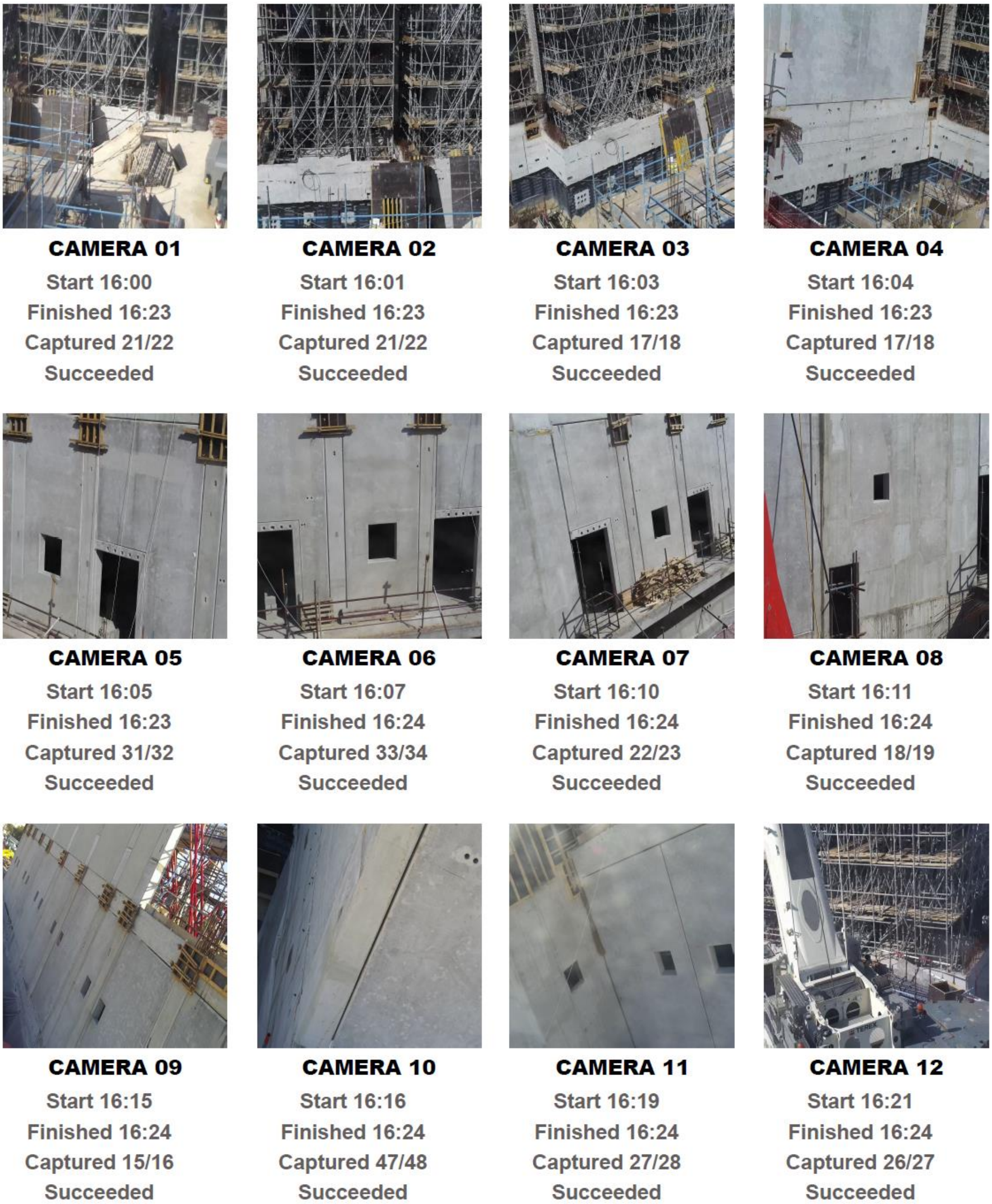


Figure 8.11: The number of captured images in one event and the duration for shooting

At the project onset and prior to starting any construction activity, the construction schedule was detailed in a way to allow the monitoring of each construction element. Therefore, the construction elements were decomposed to chunk elements. In doing so, Autodesk Navisworks was used to assign a unique code (element ID value) to each element in accordance with the coding system of the baseline program, as shown in Figure 8.12, part of the baseline program appended in Appendix 9.

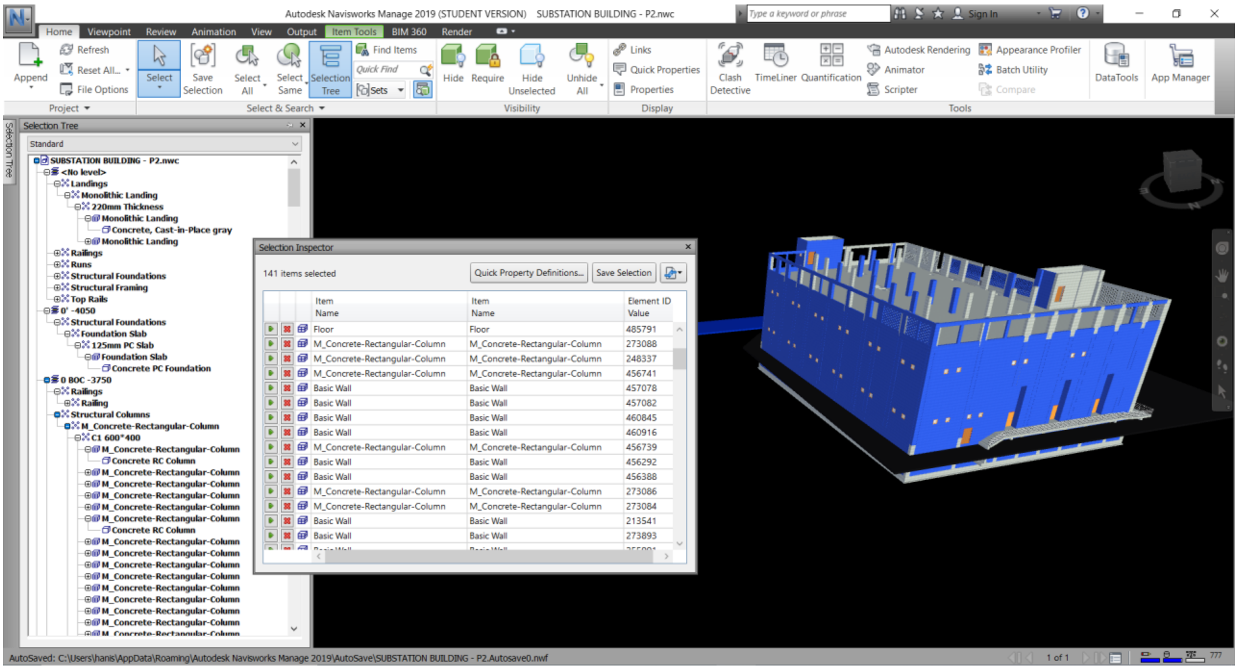


Figure 8.12: Screenshot for the baseline 4D BIM model

To ensure smooth performance, the AMAC system adhered to the following predefined rules:

1. The contractor's management team and staff thoroughly reviewed and accordingly committed to follow the construction sequences of the 4D BIM model. For example, according to the program sequences, the contractor should cast the plane concrete first, and then the raft foundation. Similarly, columns start after raft foundation finished. However, beams and slab are casted together at the same time.
2. The contractor assigned weighted values for each activity; these weights formed the basis of determining the percentage of completion for each activity and the overall progress status of the project.
3. Construction logic has been applied to overcome the inevitable static occlusions and to enhance the system's accuracy. For example, once the system detects the commencement of concrete works for a slab, this is automatically interpreted as all columns have been cast even if the camera failed to capture any of the columns' tips due to permanent static occlusions such as scaffoldings, shuttering or the like.
4. If during the construction should the construction schedule require revisions due to change orders or any arisen force majeure resulting in either additions or omissions for any of the construction activities. Consequently, and forthwith, the 4D BIM model

must be revised to avoid any disturbance to the system. Once the revision is completed, the AMAC system is designed to allow recalculation of the overall percentages according to the revised activities.

5. Indeed, the AMAC system is flexible to accommodate any number of revisions for the program as it only considers whether the activity started, did not start, fully or partially complete. Accordingly, its main functionality is comparing the progress status i.e. as-planned against as-built to calculate the percentage of the progress status according to the aforementioned predefined rules.
6. The weighted values for excluded works, such as the finishing and electromechanical works, were defined as zero and the completion dates for these activities not considered for comparison against the start dates. Therefore, whilst these activities appear in the 4D viewer, they did not contain any information and excluded from progress updates. This is clearly shown in the following Figure 8.18, whereas, the AMAC system did not consider the activity ***ID: WHRD-Const-1100*** in any of its computation processes mainly because it is painting and finishing works.

8.1.7 Demonstration for the distinctive features of AMAC system

The system was designed to be easy to use and accessible from anywhere 24/7 for the authorised personnel (the system's users). The system consists of seven screens, of which, five screens are dedicated to display progress updates and information about the project.; these five screens were shared with all of the users of AMAC system.

The other two screens were controlled and could only be accessed by the system administrator, that is the researcher, chiefly as they had enhanced access to the system and could control its settings. These two 'administrative' screens are the "***AMAC setting***" screen shown in Figure 8.13 which allows; changing the capture times, the addition or removal of the captured events where appropriate, the ability to grant or withdraw access to/from the users and amendment of contact details for daily notifications. The ability to input capturing off-times such as the weekend and the public holidays, and to define of the destination (folders) for saving the captured images, and lastly to define the kick-off date for the system, can be found in these screens.

The second module that was not shared with the users is "**Capture site now**" this module allows the administrator to capture images at any time other than the predefined two events.

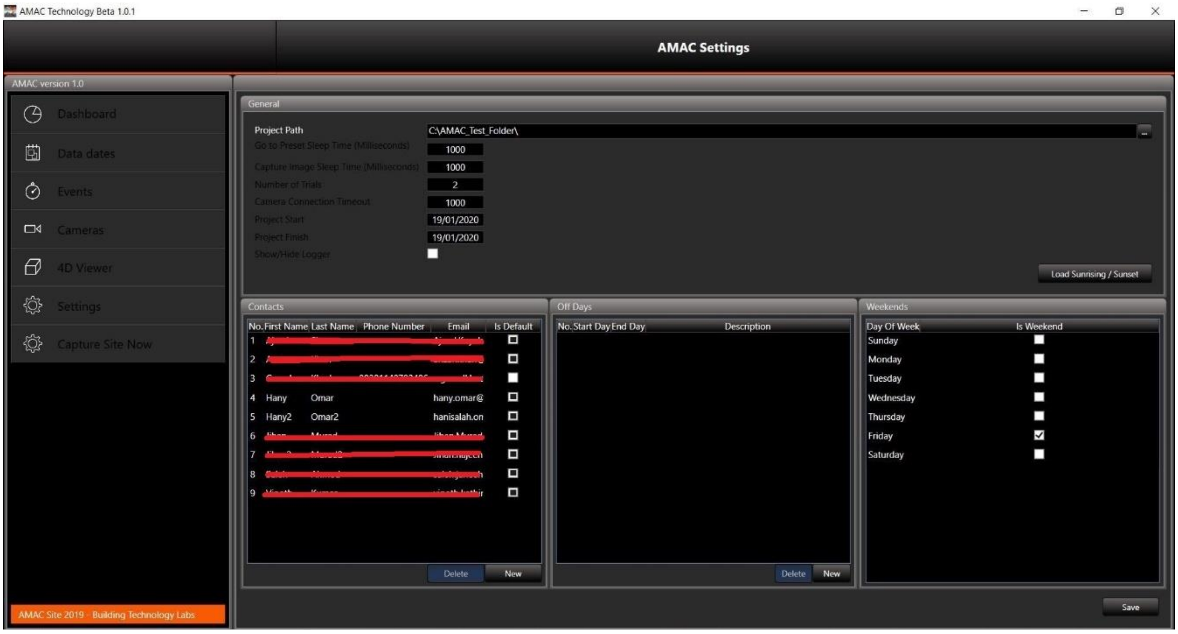


Figure 8.13: Features controlled only by the system administrator

The other five screens start with the "***Dashboard"*** shown in Figure 8.14 in which the overall progress status is shown in percentage terms in three pie charts. The first pie chart represents the *project planned progress*, and the second represents the *project actual progress*, with the third depicting the difference between the planned progress and actual progress.

The green bar chart in Figure 8.14 denotes the planned progress start and finish dates, whilst, the red bar chart depicts the actual project start date and expected completion date according to the actual construction progress.

As explained previously in Chapter 7 within the pilot project study, the "***Dashboard***" shows only the status for the deviated activities in percentage. For example, in Figure 8.14 the activity: ***WHRD-CONT-4240*** AMAC system shows it suffered delays of ***87.7%*** because its *early finish date* has already elapsed. However, the activity had not started yet, which is clear as the system does not show the red bar that indicates the start date of the activity.

Although, the system depicts the activity ***WHRD-CONT-4240*** as suffering from a 87.7% delay, the overall project status is 3% ahead, compared with the as-planned schedule. This is mainly due to the low weighting value for this activity and it obviously does not form part of the critical path as it is an installation of precast units in a trench. Moreover, the absence of the red bar affirms that the *Late Finish* date for this activity has not elapsed yet.

This delay (i.e. 87.7%) caused by a minor activity was obviously covered by several significant activities completed ahead of their planned schedule.

On the other hand, this 3% can be potentially reduced or even converted to overall delays for the overall project status, if the *late finish* date of this activity elapsed, without taking an action to recover the incurred delays for the activity ***WHRD-CONT-4240***.

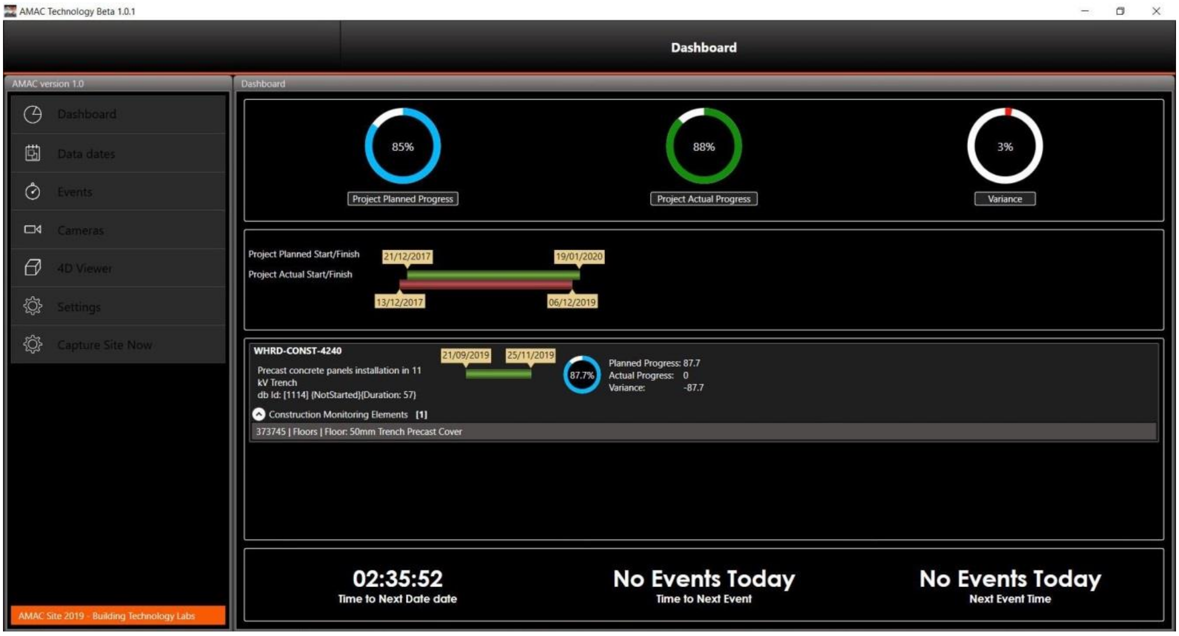


Figure 8.14: Dashboard for AMAC system

The second screen in shown Figure 8.15 is the "***Data dates***" which illustrates the status of each camera; how many images were captured and the start and end times for capturing events. It also displays the number of pre-sets (the designated range of motion for each camera according to the predefined rule of 3^{o} horizontal and 5^{o} vertical).

This screen also shows the dates of each capture; however, the most important part of this screen is to alert the administrator if the camera fails to capture an image(s) due to an electric outage or the like. This may result in the administrator adding another event manually or to capture the site at that point. Due to this feature, any captured image may be retrieved at any time throughout the project lifecycle.

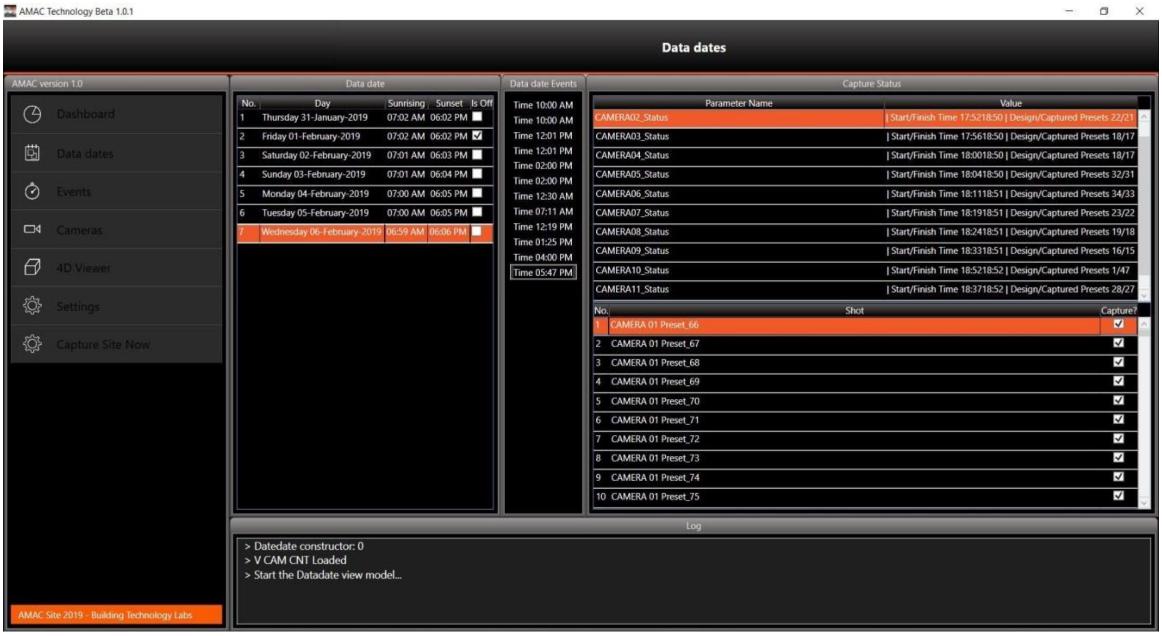


Figure 8.15: AMAC system, data date

The third screen is dedicated to "***Events***", as previously stated and as shown in Figure 8.15, there are two main events when the cameras capture images automatically; one hour after sunrise and one hour before sunset. In addition, there is one more event at 4:00 PM which will take place automatically, if erratic photos exceed 15% of the captured photos at the first event. Erratic photos are removed by the software if they are not clear enough.

The calendar of Dubai was synchronised with the AMAC system so as to recognise the times of sunset and sunrise, and additionally, Fridays and public holidays wherein the system is automatically turned off for these days.

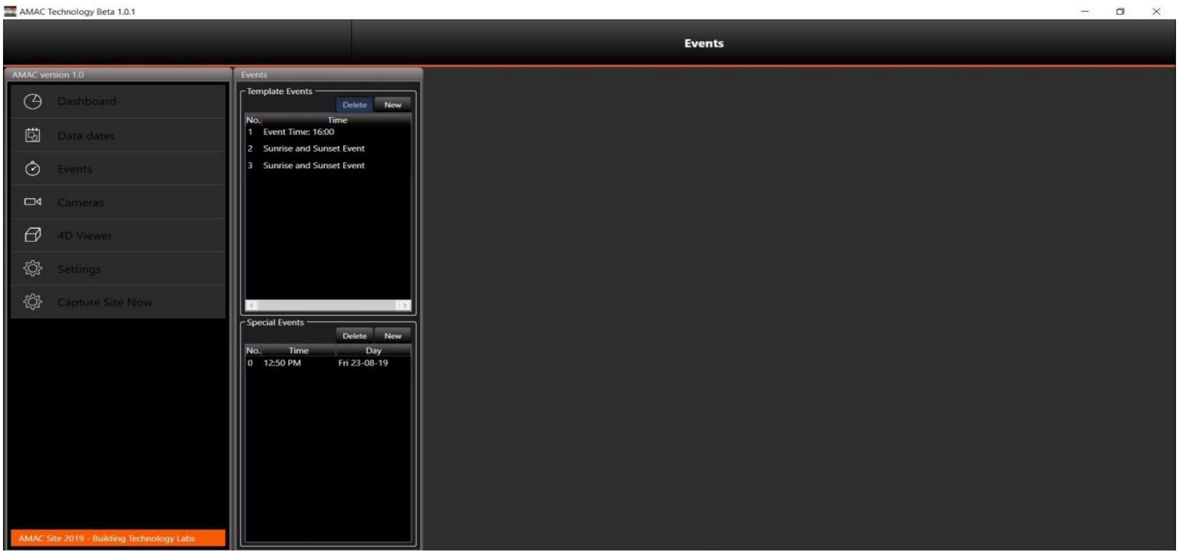


Figure 8.16: AMAC system, and events

The fourth is the "***Cameras"*** screen portrayed Figure 8.17 which allows users to virtually login to any of the twelve cameras to watch a live stream of the site from anywhere in the world at any time; this feature allows the system's users to control the camera to pan, tilt, and zoom for checking any specific activity or sometimes to investigate safety violations.

This feature enabled the owner's staff to check the ongoing activities from their offices without travelling to the site. Additionally, this feature enabled a better control on the adherence of the safety measures on the construction site by monitoring and watching the site at any time. Costs and time were saved due to this feature with a significant reduction in staff travelling to site.

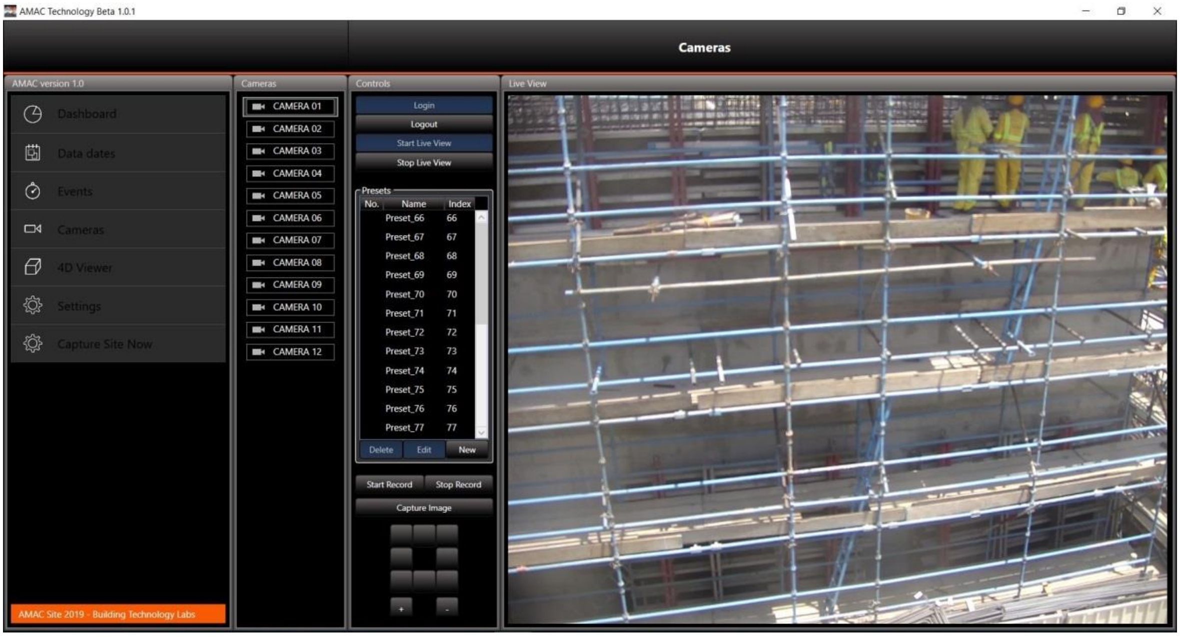


Figure 8.17: AMAC system, cameras

The fifth screen, "***4D Viewer"*** was considered the most important feature of the AMAC system according to the contractor, sub-contractor, consultant and owner's feedback. This feature illsutrated in Figure 8.18 enabled the site staff to recognise in detail the progress status for each construction element, and accordingly they were able to see progress projected onto the 4D BIM model. The users recognised the actual progress status in percentage terms and the variance for each activity. The following explains the progress status via the 4D viewer.

- A negative sign (-ve) denotes the activity suffering from delays
- A positive sign (+ve) denotes the activity is ahead of its planned schedule.
- In the case the progress is absolutely on schedule, the system is designed to show neither a negative nor positive sign.

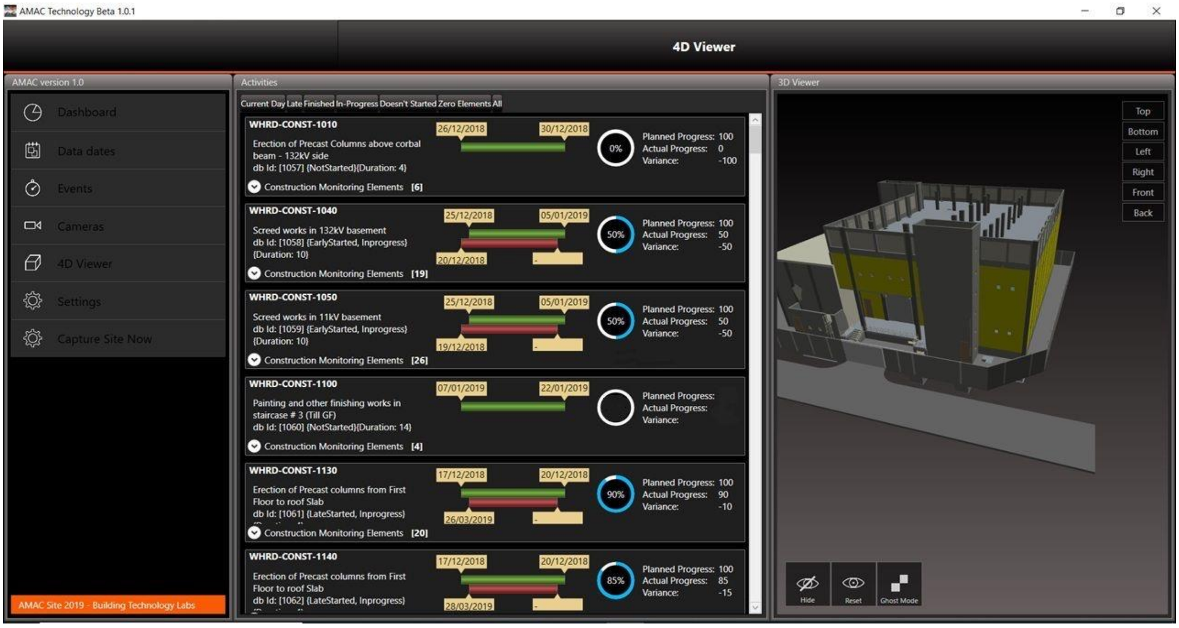
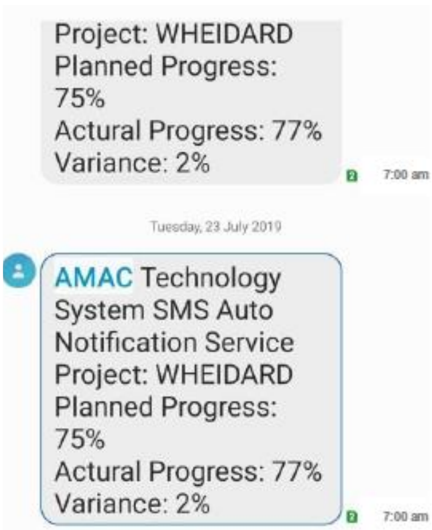


Figure 8.18: 4D viewer of AMAC system shows the progress status for construction activities

8.1.8 Notifications for the progress updates

If the as-built and as-planned are similar, it means that there is no deviation and therefore, notification is not required. However, if any deviation is detected due to a discrepancy between the as-planned and the as-built, automatic notifications are sent to the decision-makers.

The system considers a “deviation” as any activity ahead of or behind the as-planned schedule. Once the progress status is updated, the notification automatically alerts the concerned parties via SMS and email as shown in Figure 8.19 and Figure 8.19 respectively.



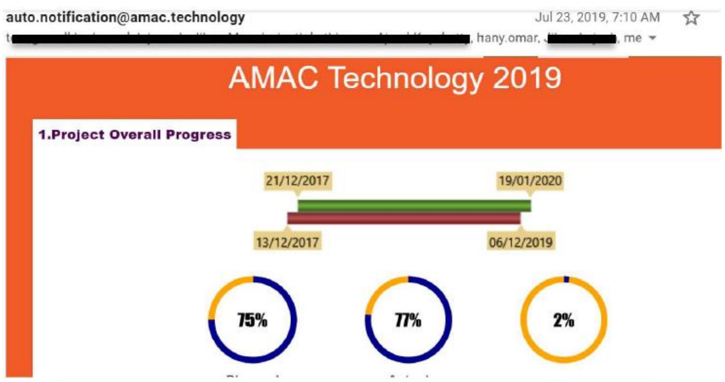


Figure 8.19: Screenshot for auto-notification SMS **Figure 8.20**: Screenshot for auto-notification email

The following section discusses the effectiveness of the AMAC system as validated by a representative sample of construction project professionals who represent the users of the system in the case study. Additionally, the system's accuracy is compared against similar systems and the approach that is traditionally adopted by DEWA for its projects.

8.2 Data analysis, Results, Finding and Discussion

8.2.1 Validation of AMAC system

Validating the effectiveness of the AMAC system with a representative sample of construction project professionals, will enable generalisation of the system for the entire construction industry.

Michael *et al.,* (2011, p.87) claimed that "*validation*" refers to activities that ensure the exact product is built by determining whether it meets customer expectations and fulfils specific user-defined intended purposes. This definition is supported by IEEE STD-610 (2010, p.392), determining validation as demonstrating that the system can be utilised by users for their specified tasks. In the same context, ISO 9000 (2005) considers validation as the process of examining a product to determine conformity with the users' needs.

Pursuant to the widely adopted principle articulated by Bevan (1998), whereas, he stressed the necessity of validating the final version of the developed product by the real users to ensure system meets with their expectations in the real world.

To that end and to ensure rigorous validation of the AMAC system, a comprehensive research study was conducted on the approaches taken validating systems similar to the AMAC. The comprehensive study revealed about, several researchers have followed one of two methods, either theoretical or empirical validation.

Nevertheless, most of published research shows that, either one of the two methods was adopted to validate the system; however, to increase reliability of the validation testing, this research study validated the AMAC system adopting both validation methods.

Accordingly, prior to validation of the AMAC system, it is necessary to have knowledge of the system(s) or the approach(es) that DEWA is following for updating its progress status and then detecting and reporting delays for its projects.

8.2.2 Empirical validation- Comparison between AMAC system and DEWA conventional method for progress updates and delays detection

The literature review revealed that the approach developed by Seddon and Kiew (1996) for validating systems similar to AMAC has been widely adopted by various researchers such as (Armstrong *et al.,* 2005; Thomas-Alvarez and Mahdjoubi, 2013; Martins *et al.,* 2015; Mahamadu, 2017).

Seddon and Kiew (1996) proposed an approach for empirical validation of developed systems, which would involve testing the final version of the AMAC system with real users that represent a sample of the population to allow for further generalisation. For reliable results of the empirical validation, it is recommended that, the users of AMAC system should have a solid experience of using the traditional approach that is followed by DEWA for detecting and reporting the delays in its construction projects.

According to Oshishi *et al.,* (2008) empirical validation is a fundamental process to ensure the results from the developed system is reliable for generalisation to the total population.

Accordingly, empirical validation will be implemented using two stages as follows:

Stage 1: involved quantitative data collection from the users of AMAC system in the case study to validate the effectiveness of the system via two online surveys. The first survey will assess the effectiveness and challenges and limitations of the conventional approach that DEWA follows to detect and report the delays for its construction projects.

However, the second survey will assess the effectiveness, challenges and limitations of the AMAC system, according to the experience from the same users at the 132/11 Kv substation case study. The quantitative data of the two online surveys will be analysed statistically using SPSS to validate the effectiveness of the AMAC system as a ready to use system for detecting and notifying the delays in the construction industry.

Stage 2: involved comparing the performance records for all 132/11 Kv electrical substations in the past 10 years against the performance of the 132/11 Kv case study wherein, the AMAC system employed as the mainstay project management tool for detection of delays and the notification process. The performance was compared using the most common, tangible, and recorded criteria for measuring the success of construction projects (i.e. the cost and time).

The following section introduces the conventional approach that DEWA followed in its construction projects, including the 132/11 Kv electrical substations built in the past 10 years.

8.2.2.1 The current approaches that DEWA adopt for monitoring its construction projects

DEWA does not use only one method for monitoring, controlling and updating the progress for its construction projects. Whereas, most of the sites are still using the conventional method of paper and pen, with the entire process is manual until the point of pulling together the progress report which is done with the aid of Primavera P6 as detailed in Chapter 3. However, a few sites do use a semi-automated approach via tablets for data collection from site.

Semi-automated approach: In line with its relentless endeavours to reduce the risk of human error and subjectivity, whilst saving time and costs and improving accuracy; DEWA introduced the use of tablets to reduce human intervention as shown in Figure 8.21.

The newly utilised approach deemed as a quasi-automated system, as the inspector must still visit site to visually inspect and estimate the construction progress to complete the pre-prepared checklists accessible on the tablet.

As with the conventional methodology, all of the processes in the semi-automated approach are subject to the inspector's judgment and estimation in terms of the percentage of the completed works, and additionally, the data is inputted manually.

8.2.2.2 The reported limitations and challenges of DEWA's approaches

As part of the researcher's remit as an employee of DEWA (head of the technical development unit), the users of the semi-automated approach reported into to the researcher. It is well known within the DEWA project teams, that the only advantage of using the tablet system is that it has shortened the paper-pen long process. Wherein the data fed into the tablet is shared instantly with the relevant employees at DEWA through its platform. Therefore, there is no need to integrate and prepare the data in the office, which is the only process that is no longer required in the manual approach.

However, the system's users have reported the following limitations and challenges with the implementation of the semi-automated system.

- The pre-prepared checklist in the tablet, frequently, do not include all of the site activities which accordingly results in the inspector reverting back to the paper-pen approach for data collection and to disregard the tablet which is then deemed not fit for purpose. According to the inspectors, missing the construction elements in the checklist tends to reoccur frequently, mainly because the checklist is prepared manually prior to starting the project.

- Inputting data collected from one inspection session takes 30-45 minutes without attaching any photos. To undertake the process with photos usually takes more than 60 minutes. However, the system often fails to allow the upload of photos.
- It is difficult to retrieve the data after 15 days as the system is designed to discard all data after 15 days.
- Switching between screens is tedious and takes approximately 10 seconds just to switch from one screen to another.
- It is not easy to rectify or amend the entered data as it is instantaneously shared with others via the central platform. Consequently, any required rectifications for entered data necessitate special approval along with justification from the line manager, which accordingly exposes the inspectors to the risk of being evaluated as unqualified or incompetent in their job.

  Indeed, this is the main reason for which inspectors avoid using the tablet; and consequently, they prefer using the paper-pen approach using numerous excuses such as weak internet signal to justify their actions to management. With the manual approach they have full control to amend the data until the report is prepared.
- As the semi-automated system still suffers from significant limitations and challenges, DEWA has not mandated this approach as yet, and accordingly, almost all the construction sites are still embracing the manual approach for data collection and reporting.

Due to the above limitations and challenges, the presiding approach used at DEWA construction sites for the detection and reporting of delays, is the paper-pen based approach.

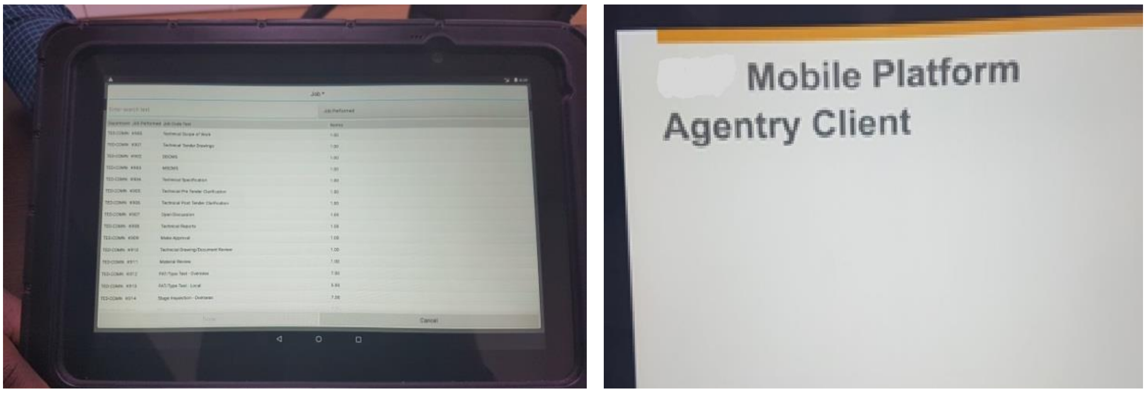


Figure 8.21: DEWA's Tablet used to update progress status

8.3 Empirical validation- Stage 1: Data collection

According to Thomas-Alvarez and Mahdjoubi (2013, p.199) validation involves the comparative study of the developed system against conventional approaches. In this context, the literature study revealed that empirical validation could be accomplished by collecting the users' feedback about their experience of the developed system through online surveys to enable testing and validating the effectiveness of those systems.

The same approach of Thomas-Alvarez and Mahdjoubi (2013) has been followed to validate the AMAC system, largely due to the similarities whereby they validated and measured the effectiveness for their developed portal in a real-life case study with the end-users. Likewise, the AMAC system was rolled out as the mainstay tool employed to detect and notify any delays in a real-life case study. Accordingly, its efficiency and effectiveness can be easily measured from the users' feedback.

Furthermore, several researchers such as Seddon and Kiew (1996), Zalzelenchuckand Boiling (2003), Armstrong *et al.,* (2005), Thomas-Alvarez and Mahdjoubi (2013) and Martins *et al.,* (2015) adopted the online survey for testing and validating their developed systems empirically, as the online survey is the most efficient approach which can definitively measure the users' experience and feedback statistically.

Subsequently, the users of the AMAC system were asked to complete an online survey to rate the effectiveness of the system for identifying construction overrun and ensuing notification process in comparison with the conventional methods followed by DEWA in similar projects.

8.3.1 Participants of the online survey

The participants involved in this stage of validation were users of the AMAC system in the case study (the 132/11 Kv substation).

Securing a large enough sample size that allows for accurate analysis using SPSS, has resulted in including the first and second tiers of management staff (i.e. executive staff, senior managers, PM, deputy PM, construction manager, principle engineers and senior engineers). The sample size and range of roles was designed to provide a representative selection of participants involved in construction projects involving contractors, subcontractors, consultants and owners.

To determine the optimal sample size to authenticate and enable the validation process and generalisation of the research results, the following formulas were applied:

1. Calculation of the sample size for population by using the following formula developed by Cochran (1977):

$$\text{Necessary Sample Size} \quad \mathbf{SS} = \frac{(\mathbf{Z\ score})^2 \times \mathbf{p}(\mathbf{1}-\mathbf{p})}{\mathbf{m}^2} \quad \text{......... Equation}$$

Where:

Z score: 1.96 the most common confidence levels (1.96)

p: population proportion (assumed to be 50%=0.5)

m: margin of error (generally taken as 10%)

$$\text{Necessary Sample Size (S)} = \frac{(1.96)^2 \times 0.5(1-0.5)}{0.1^2}$$

$$\text{Necessary Sample Size (S)} = \frac{(1.96)^2 \times 0.5(1-0.5)}{0.1^2} = 96.04$$

Necessary Sample Size (SS) =96.04

2. Adjust the sample size to the required population. The participants in this survey must have experience of the conventional approach for monitoring and controlling the delays in DEWA 132/11 kv substation projects, hence this expected population is estimated to be 60 (the management staff). This number is selected as the target sample is limited to just the first and second tier management staff committed to the project, and practically, 60 is assumed as a realistic finite population.

$$\textbf{Adjusted sample size} = \frac{S}{1+\frac{S-1}{population}} \text{.... Equation}$$

$$Adjusted\ sample\ size = \frac{96.04}{1+\frac{96.04-1}{60}}$$

$$Adjusted\ sample\ size = \mathbf{37.17}$$

Accordingly, the minimum required sample size that provides confidence in the results and allows for generalisation of the findings is **38** participants.

However, to avoid any bias towards any of the involved specialities, the required sample size for the participants of the online survey was determined to be 40 instead of 38 to enable an equal distribution of the four specialities to express their feedback. Thus, the sample size is 10 contractors, 10 sub-contractors, 10 consultants from the supervision team and 10 reflecting the project owner's perspective.

These 40 participants were engaged and trained on how to use AMAC system at the project outset. At the end of the project, an online survey was administered to those users of the

AMAC system to assess the effectiveness of the system based on their experience throughout the case study. The following table describes the participants' profile.

Table 8.1: Profile for the participants of the online survey (AMAC system users)

Participant code	**Designation**	**Specialty**	**Experience (Years)**	**Participants' experience for constructing substation (years)**
OA	Vice president	Owner	23	23
IU	Director	Owner	24	20
KA	Senior manager	Owner	22	20
HO	Project director	Owner	21	20
JA	Projects manager	Owner	21	20
AA	Civil Manager	Owner	23	19
VK	Senior engineer	Owner	18	10
AK	Senior engineer	Owner	15	10
AS	Site engineer	Owner	12	10
SK	Site engineer	Owner	13	10
WA	Vice president	Consultant	29	8
WR	Construction manager	Consultant	35	10
RA	Director	Consultant	27	9
MA	Senior projects manager	Consultant	25	4
KN	Projects manager	Consultant	26	15
	Senior quantity surveyor	Consultant	30	8
IUR	Resident engineer	Consultant	27	20
NA	Assistant resident engineer	Consultant	16	6
OAI	Senior site inspector	Consultant	20	10

AA	Site inspector	Consultant	9	5
RD	General manager	Contractor	37	25
SU	Director	Contractor	30	15
MH	Project manager	Contractor	33	20
FA	Assistant project manager	Contractor	24	15
KY	Construction manager	Contractor	19	15
KT	Site agent	Contractor	20	16
PJ	Senior site engineer	Contractor	16	12
LT	Senior site engineer	Contractor	19	15
SM	Site engineer	Contractor	7	3
AN	Quantity surveyor	Contractor	28	18
AS	Project manager	Sub-contractor	26	25
MK	Deputy project manager	Sub-contractor	25	14
MB	Assistant project manager	Sub-contractor	27	23
AH	Construction manager	Sub-contractor	25	17
SS	Senior quantity surveyor	Sub-contractor	32	26
WI	Quantity surveyor	Sub-contractor	20	18
DI	Site agent	Sub-contractor	22	19
LK	Senior site engineer	Sub-contractor	23	19
OT	Site engineer	Sub-contractor	10	9
MR	Site engineer	Sub-contractor	8	4
Average			**22**	**15**

The participants of the online survey were represented equally in the sample size, and as shown in the above table, the positions of the participants are diverse and reflect all tiers including executive and senior levels - 2 vice presidents, 1 general manager, 4 directors, 2 senior managers. It also involved mid-management comprising of 12 managers/ assistant manager, and construction managers, and operational and site levels involving the site agent, senior site engineers and site engineers.

As per the above table, the overall average of the participants' experience is 22 years. Clearly all the participants have previous experience in the building of elecrtical substations, the participants' average years of experience for the electrical substation is approximately 15 years.

Fortunately, six participants who are shown in bold font in the above table, were involved in the first development stage of the pilot project case study in addition to their involvement in the empirical validation of the system within this second development stage of the full lifecycle case study.

Additionally, involving 34 new participants gives the opportunity to aggregate different opinions of the new case study to enrich the research for rigorous reliability of its findings.

8.3.2 Online survey questionnaire

Validation of the final version of the AMAC system with a larger number of users in a real-life case study at the electrical substation allowed collection of real data that reflected a usability assessment of the system. Although, the contract commencement date is 21st December 2017, the civil works actually started on 5th May 2018 and were completed on 19th November 2019.

Close-ended questions using an ordinal scale were employed to make the questionnaire as easy to complete as possible. The layout and format of the questionnaire was also given consideration in order to ensure that respondents did not inadvertently miss any of the questions. The Qualtrics survey platform was selected for the purpose of collecting the responses from the participants, as it is straightforward to formulate the questions on it and it is free. An official invitation (Appendix 3) was sent to the selected participants via emails, soliciting their participation in the study.

The first online questionnaire (Appendix 10) sought to measure the users previous experience regarding the effectiveness of the conventional approach for detecting and reporting the delays; it was sent via email to the 40 participants on 15th June 2018. This date was selected, as before this date the project staff were not fully assigned. However, the second survey concerning assessing the effectiveness of AMAC system was sent on 24th October 2019, approximately one month prior to closing out the project.

The questionnaire was developed on the basis several research projects that validated systems like AMAC, indeed, the questionnaire was developed based on the interrogations developed by Seddon and Kiew (1996), Armstrong et al., (2005) and Thomas-Alvarez and Mahdjoubi (2013) for validating their systems. The questionnaire has included an eclectic mix questions they used and that were deemed to be suitable for AMAC system; the questionnaire consisted of seven sections detailed hereinafter.

8.3.2.1 Demographics

The questionnaire started with an exploration of the participants' work specialty, and whether the participant had experience of working on DEWA 132/11Kv substation project within the last ten years. These two questions sought to ensure the ability of the participant to compare the newly developed system (AMAC system) and the conventional approach of detecting and reporting the delays.

8.3.2.2 System quality

According to Seddon and Kiew (1996, p.93) system quality is essential to recognising if there are "bugs" in the system, the consistency of the user interface, ease of use, and response rates in interactive systems. Similarly, Armstrong *et al.,* (2005) considered system quality as the system usage characteristics. In the same context, Thomas-Alvarez and Mahdjoubi (2013) considered system quality as tantamount for the use of the proposed system against other systems and conventional approaches.

Therefore, this section consisted of five questions to investigate the "*ease of use of the AMAC system*", "*whether the system is a user friendly*", "*the system is easy to learn*", "*the system lived up to users expectations*", and "*the ease of becoming skilful in using the AMAC system*".

8.3.2.3 Information quality

Juran (1988) considers information quality is free from deficiencies, this definition developed from the accuracy perspective, which resulted in that the abstracted information should be free from any errors.

However, English (1999) investigated quality from the user's angle, and thus, he defined quality as information that consistently meets customers' expectations; but notably overlooked accuracy of the information, considering accurate information redundant. As he implied the very accurate information could be useless to the user, if it does not enable the user to accomplish their task within the organisation. A later study conducted by Gustavsson and Wänström (2009, p.327) integrated both definitions forming a new definition as "the ability to satisfy stated and implied needs of the information users".

This concept corresponds to the definition devised by Seddon and Kiew (1996, p.93), whereby they considered information quality concerning characteristics such as timeliness, accuracy, relevance, and format of the information.

This section of the questionnaire included nine questions seeking to investigate information quality in terms of "*information presented in a useful format*", "*satisfaction of the system's accuracy*", "*the clarity of which the system displays the information*", "*the system provides sufficient information*", "the *system provides accurate daily progress updates*", " *obtaining the required information on time*", "*the system provides reports responding to exactly what is needed*", "*the system provides precise information that is needed*", and "*the system provides information that meets the user's needs*".

8.3.2.4 Perceived usefulness

Perceived usefulness is the degree to which a person believes that using a specific system would enhance their job performance (Davis, 1989, p. 320). Developed from a more focused insight of gaining greater advantage, Armstrong *et al.,* (2005, p.5) considered perceived usefulness as assessing whether the used system saved time and cost. Indeed, assessing the perceived usefulness from Davis' (1989) perspective implicitly assess whether the used system saved time and cost, as being claimed by (Armstrong *et al*., 2005).

It is crucial to assess the usefulness of the AMAC system in saving the project cost and time.

Thus, this section includes six questions designed in line with the questionnaires developed by Davis (1989) and Seddon and Kiew (1996) to assess the usefulness of the AMAC system in terms of "*ability to quickly accomplish daily tasks*", "*ability to efficiently accomplish daily tasks", "improvements in the user's performance", "productivity increased", "enhancements of the effectiveness in the project",* and *"easier to do my tasks".*

8.3.2.5 Overall satisfaction

Overall satisfaction is regarded as one of the most important measures to assess the success of any newly developed systems (Xiao and Dasgupta, 2002). Therefore, the literature is rich with a plethora of researchers who have assessed the users' overall satisfaction for systems similar to the AMAC system such as (Ives *et al.,* 1983; Bailey and Pearson, 1983; Benson, 1983; Baroudi *et al.,* 1986; Doll and Torkzadeh, 1988).

The literature study explicitly demonstrates that the shared measures amongst those researchers are their assessments of the effectiveness and the users' overall evaluation of their satisfaction.

Accordingly, this section entails six questions assessed the role that AMAC system played to "*improve the user's performance in carrying out their responsibilities", "improve the efficiency", "improve the effectiveness", "measure the users' satisfaction of the system", "system is fully automated" and "the updates are reliable".*

8.3.2.6 Usage of the system

According to Thomas-Alvarez and Mahdjoubi (2013) the "*frequency of use*" is a good estimate for measuring the success of the developed system, whereby, they have measured the success of their developed portal system based on the number of users. Likewise, Seddon and Kiew (1996) established that, the number of hours a system is used conveys the usefulness and success of the system, especially when usage of the system is not compulsory, which means, the system that attracts more users offers strong evidence of the success of the system. Seemingly, the frequency of system use is a good indicator of the usefulness and thus success of the system.

This section includes four questions that assessed the usage of AMAC system, which were developed in light with what (Seddon and Kiew, 1996) have developed.

This section assessed the usage of the AMAC system in terms of "*the frequency of use of the system", "the users' choice to continue to use the system even if it is not mandatory"* and *"the feature that attracts the user to use the system".*

8.3.2.7 Importance of the system

Seddon and Kiew (1996) and Armstrong *et al*., (2005) have assessed the users' perceived importance of the system from three main dimensions, which are relevant to the user's task, usefulness and the ease of use.

Accordingly, this section includes two questions similar to what have been developed by Seddon and Kiew (1996) which was seen as the most appropriate, largely as they have been used to validate a system similar to the AMAC system.

These questions were customised to fit AMAC for assessing the user's experience pertaining to the superiority of AMAC system over the conventional approaches for detecting and reporting the delays in construction projects.

These questions assessed the importance of AMAC system in terms of "*importance*", *"relevance"* and "*usefulness"* of the system.

8.3.2.8 Refinement of the validation survey

To test the accuracy, suitability, appropriateness and comprehensibility of the formulated questions, in addition to testing the language used and clarity in the presentation of the questionnaire; a pilot survey was sent to 10 randomly selected participants from the total 40 participants, representing the senior management, mid-senior management, management and operational levels.

Prior to sending out the pilot questionnaire survey, communication via a phone call was conducted with each one of the selected ten participants where the aim of the pilot survey was explained to them. A follow-up e-mail was sent containing the link for the pilot survey via Qualtrics.

The survey asked them to review the structure, contents, the language and the design of the questionnaire by noting down their comments and suggestions to make the survey easier and clearer and therefore to achieve its objective. Additionally, they were asked to indicate the time taken to complete the survey.

Subsequently, the constructive comments received from the participants of the pilot survey assisted the researcher to refine the questionnaire and to develop the final version of the survey.

The final version of the survey was sent to the 40 participants and the responses were collected anonymously via the Qualtrics survey platform and were then analysed statistically using SPSS for both surveys.

The statistical data analysis allowed comparison of the results using the Mann–Whitney *U* test to assess the effectiveness of the AMAC system against the conventional approach that was followed by DEWA for the past 10 years.

According to the records, DEWA built 48 electrical substations between January 2010 and April 2020 of which the details for these substations are included in (Appendix 11).

8.3.3 Analysis of quantitative data

The main objective of this section is to investigate and compare the effectiveness of the AMAC system against the conventional approach, and hence, an invitation letter containing the link for the online survey questionnaire was distributed by e-mail to the 40 users of the AMAC system. The Likert scale (1=strongly agree and 5=strongly disagree) was utilised as an assessment tool to measure the respondents' feedback of each question.

The Mann–Whitney *U* test was selected as the analysis technique for the responses collected from the 40 participants, mainly as this technique allows the investigation and comparison of opinions from a group of users regarding two different experiences.

Pett (1997) established that the Mann–Whitney U test is a nonparametric test which has been widely adopted for project management and marketing research when comparing the opinions of a group of people towards certain subjects.

Several researchers such as Yang *et al.,* (2007), Yang and Hsie (2011), Thomas-Alvarez and Mahdjoubi (2013), Eiris *et al.,* (2020) have employed the Mann–Whitney *U* test as an effective statistical analysis technique to realise the distinctions of their developed systems. Whereby, they compared the effectiveness of their developed systems by testing the users' experience of their system against other systems. An additional reason of adopting the Mann–Whitney *U* test is that it is the most suitable statistical test analysis for the non-normality distribution of collected data (Mann and Whitney, 1947; Eiris *et al.,* 2020).

The participant responses were analysed using SPSS to assess the effectiveness of each approach for the detection and notification of delays.

Although only one group of the 40 participants were involved in the two surveys; the first survey questioned the effectiveness of the conventional approach whilst the second examined the effectiveness of the AMAC system. Yet, they were named as "**group A**" to represent the responses pertaining to the ***conventional approach***. And "**group B**" to represent the responses for the AMAC system.

According to Field (2013) the following criteria are used to determine the results of Mann–Whitney U test:

i. The smaller the U value means the bigger the *difference/disagreement* between the two groups, and the bigger the U value means the smaller the *difference/disagreement* between the two groups.
ii. $U = 0$ means no agreement between the two groups, which means both groups have opposite opinions stemming from their experience.
iii. The bigger the arithmetic value of $-Z$, the higher the significant difference between both groups.
iv. The higher the score of the mean rank the lower the satisfaction, conversely, the lower the score of the mean rank the higher the satisfaction. And the bigger the gap of the mean rank between the two groups, a significant difference exists.

The following Table 8.2 describes the participants' satisfaction for each approach.

Table 8.2: Analysis of respondents data

Statement	Group	Mean rank	Sum of ranks	Mann–Whitney *U*	Wilcoxon W	*z*	*p* value (two-tailed)
System quality	A	60.49	2419.00	0.500	820.50	-7.945	0.000
	B	20.51	820.50				
Information quality	A	60.50	2420.00	0.000	820.00	-7.978	0.000
	B	20.50	820.00				
Perceived usefulness	A	60.50	2420.00	0.000	820.00	-8.003	0.000
	B	20.50	820.00				
Overall satisfaction	A	60.50	2420.00	0.000	820.00	-8.032	0.000
	B	20.50	820.00				
Importance of the system	A	60.50	2420.00	0.000	820.00	-8.033	0.000
	B	20.50	820.00				

8.3.4 Data analysis

To compare the respondents' level of satisfaction for the conventional approach against AMAC system for the detection and notification of delays in construction projects, the collected data was analysed using the Mann–Whitney *U* test via IBM SPSS Statistics 26.0 software.

The AMAC system and the conventional approach will be named idiomatically as the *"approaches"* hereinafter for general analysis, however, detailed analysis will differentiate and make it clear which approach is meant.

The Mann–Whitney *U* test was conducted to check the significant difference between the respondents' level of satisfaction in the two groups. ***In case*** the analysed results show the significance of $\boldsymbol{P > 0.05}$ that means both groups are satisfied with the two approaches and both approaches are effective in detecting and notifying the delays. And accordingly, there are no significant differences between the conventional approach and the AMAC system, either of them can be used, as it is effective to detect and notify the delays.

However, ***in case*** the analysed results show the significance of $\boldsymbol{P < 0.05}$, that is interpreted as being a significant level of dissatisfaction towards one of the two approaches, as it is according to the participants' responses that one of the two approaches is not effective and tends to fail in detecting and notifying the delays efficiently.

For further elaborations of the results, statistical based-descriptive analysis of the mean and standard deviation was conducted to recognise which of the two approaches is the non-effective approach.

In case the statistical and descriptive results supported the AMAC system, that will positively advance its validation as an effective system for detecting and notifying the delays instantly in the construction industry.

8.3.4.1 System quality

As shown in Table 8.2, the small value of $U = 0.5$ demonstrates there is an overall disagreement between the two groups for system quality, which means the respondents are satisfied with one "*approach*" and not satisfied with the other.
And accordingly, a further investigation was made for each interrogation, and it was found that, there is a slight agreement between both groups for one of the questions, "***the system is easy to learn***" for both the AMAC system and the conventional approach.

Indeed, this is plausible, mainly because the conventional approach is easy to learn as the respondents have been familiar with the system for a long time. The AMAC system is also easy to learn.

Moreover, the analysed data for the ***"system quality"*** of the (2-tailed) significance resulted in a value of $p = 0$ which is < 0.05 which means there is a significant level of dissatisfaction towards one of the two compared "*approaches*".
The value of $p = 0$ indicates that the effectiveness of both "*approaches"* are considered significantly different which means, the two groups have significantly different opinions about the system quality as one approach is considered effective whilst the other considered ineffective.
To recognise which one is effective, the value of the mean rank is interpreted, whereas the mean rank of "group A=60.49" which is significantly higher (almost three folds) than "group B=20.51", accordingly the results suggested that, the system quality and effectiveness of the AMAC system outweighed the same of the conventional approach.

8.3.4.2 Information quality

The (2-tailed) significance shows a value of $p = 0$ which is < 0.05 indicating that there is a significant statistical difference between the two groups concerning the effectiveness of the *information quality* between the conventional approach and AMAC system. Furthermore, the value of $U = 0.00$ suggests contrasting opinions about the effectiveness of both approaches. This controversy is further clarified by the value of the mean rank of "group A=60.50" which is significantly higher, almost triple the value of "group B=20.50" which suggested that, the effectiveness of the AMAC system in terms of "*information quality"* surpassed the conventional approach.

8.3.4.3 Perceived usefulness

The value of $p < 0.05$ indicates there is a significant statistical difference between the two groups concerning the effectiveness of the *perceived usefulness of* the conventional approach and AMAC system. Additionally, the value of $U = 0.00$ indicates there are opposite opinions about the usefulness of both "*approaches*".
Ultimately, the value of the mean rank of "group A=60.50" is significantly higher than group B=20.50 which suggests that, the effectiveness of AMAC system in terms of "*perceived usefulness*" surpasses the conventional approach.

8.3.4.4 Overall satisfaction

The value of $p < 0.05$ indicates there is a significant statistical difference between the two groups concerning to the users' satisfactions for the conventional approach and the AMAC system. Moreover, the value of $U = 0.00$ suggests there are opposite opinions of the users towards the both approaches.

The value of the mean rank of "group A=60.50" is significantly higher than "group B=20.50" which suggests that, the effectiveness of AMAC system in terms of "*users' overall satisfaction"* is significantly better than the conventional approach.

8.3.4.5 Importance of the system

The value of $p < 0.05$ suggests there is a significant statistical difference between the two groups pertaining to the users' perceptions for the importance of the conventional approach against AMAC system. This is supported by the value of $U = 0.00$ which indicates there is a significant difference of the users' preference of AMAC system over the conventional approach.

Additionally, the value of the mean rank of "group A=60.50" is significantly higher than "group B=20.50" which suggested that, the effectiveness of AMAC system is significantly better than the conventional approach.

8.3.4.6 Overall remarks of the results in Table 8.2

Table 8.2 shows varied values for Z , which varies from -7.945 for the system quality, through -8.033, these values suggested the ranking of the users' preferences for the tested features of the AMAC system.

Whereby, the users found AMAC is "***significantly important***" to manage, detect and notify delays in the construction project with the highest value of ***8.033***, followed by expressing their "***overall satisfaction****"* for AMAC system with a record of **8.032**.

Additionally, the responses reflected the users' satisfaction for AMAC system as it does not require any human intervention which saves manpower and time. Accordingly, the system prevents any potential disputes and subjectivity in calculating the progress, moreover, the system reliability and authenticity of the updated progress was held in high regard.

8.3.4.7 Usage of the system

As a response to the question, "*What is the most used feature?*", it is evident that for the executives and senior managers the most used feature is the "***dashboard***" to realise the progress status. Indeed, this behaviour is supported by the analysed data collected from the interviewees at the first development stage of the pilot project in Chapter 7.

Apparently, executives and senior managers are keen to know the overall progress status from a high-level perspective without delving into the detail, primarily as this detail often requires actions that are usually the responsibilities of their subordinates i.e. the managers. However, the rest of users were keen to know the progress status, and the details of delays including its sources, therefore, the most used feature overall was the "***4D viewer***".
Unsurprisingly, using the cameras was feature least used as it was essentially required for monitoring the adherence of safety protocols or investigating accidents at site and seldom for tracking ongoing activities.
The analysed data revealed that users of the AMAC system had high levels of trust in the system's outputs, as they tended to access the system a minimum of twice daily.
Accordingly, due to tangible and distinction benefits of the AMAC system, all users expressed their strong willingness to utilise the AMAC system in their forthcoming construction projects.
Moreover, some recommended mandating AMAC as an imperative requisite management tool for the detection and notification of delays for the construction industry in the UAE.

8.3.4.8 Descriptive statistical analysis for the findings

The following Table 8.3 demonstrates the levels of satisfaction of users regarding the AMAC system, which supports the findings from the statistical analysis by the Mann–Whitney *U* test.

The descriptive statistical analysis shown in the below table demonstrates that the users strikingly prefer to use the AMAC system for detecting and notifying delays in construction projects.

The following Table 8.3 demonstrates the satisfaction levels for the users for AMAC system, whereas, **95%** of users are either strongly satisfied or satisfied with the "***quality of AMAC system***" (60% are strongly satisfied and 35% are satisfied).

Similarly, **97.5%** of users are either strongly satisfied or satisfied with the "***information quality of AMAC system***" (45% are strongly satisfied and 52.5% are satisfied).

Likewise, **100%** of the AMAC users appreciated the "***usefulness of AMAC system***", as 67.5% considered the system is highly useful and 32.5% considered it is useful.

And, the highest satisfaction level was recorded for the "***overall satisfaction of AMAC system***" for detecting and notifying the delays in construction projects, where **100%** of users appreciated the "***importance of AMAC system***" and expressed their "***overall satisfaction for AMAC system***". These two measures were equally recorded the highest scores as 72.5% of users are strongly satisfied and 32.5% are satisfied.

Table 8.3: Interpretation of satisfaction levels of AMAC system

	Number of respondents =40					
	Strongly satisfied	**Satisfied**	**Neutral**	**Dissatisfied**	**Strongly dissatisfied**	**Total**
System quality	60%	35%	5%	0.0	0.0	100%
Information quality	45%	52.50%	2.5%	2.5%	0.0	100%
Perceived usefulness	67.5%	32.5%	0.00	0.00	0.0	100%
Overall satisfaction	72.5%	32.5%	0.00	0.0	0.0	100%
Importance of the system	72.5%	32.5%	0.00	0.0	0.0	100%

The aforementioned analysis of Mann–Whitney *U* test is supported by and further elaborated on with additional descriptive analysis as follows, which was statistically derived from the responses of the two groups.

Table 8.4: Descriptive statistical analysis of the findings

Statement	**Number**	**Group A**		**Group B**	
		Mean	**Std. D**	**Mean**	**Std. D**
System quality	40	4.42	0.675	1.45	0.597
Information quality	40	4.35	0.483	1.58	0.549
Perceived usefulness	40	4.45	0.504	1.33	0.474
Overall satisfaction	40	**4.50**	0.506	**1.28**	0.452
Importance of the system	40	4.47	0.506	**1.28**	0452

For “group A” the indicated average score that measures satisfaction for the quality of the conventional approach is very low at 4.42, whereby 5 indicates the lowest level of satisfaction (5=strongly disagree/dissatisfied).
Similarly, group A has a very low satisfaction level for the conventional approach in terms of “information quality” which measured at 4.35, and “perceived usefulness” scoring 4.45, and overall satisfaction which recorded the lowest from all the results at 4.50.
Ultimately, from the “Group A” overall evaluation of the importance of the conventional approach in detecting and notifying the delays, recorded a low 4.47, where 5 means significantly unimportant. This analysis and scores reflect the users’ level of dissatisfaction towards the effectiveness of the conventional approach which evidently tends to fail in detecting and notifying the delays that result in reoccurring time delays and cost overruns. Consequently, the users are significantly unsatisfied with the effectiveness of the conventional approach.

Conversely, for “group B” the average score that measures the satisfaction for the quality of AMAC system was very high at 1.45 where 1= strongly satisfied, 2= satisfied.
Similarly, “group B” had another high satisfaction level for the AMAC system in terms of “*information quality*” which measured at 1.58, as well as the “*perceived usefulness*” scoring 1.33.
However, the scores that represent the users’ highest level of satisfaction of the AMAC system were recorded for the “*users’ overall satisfaction*” and “*the importance of the system*” with an equal score of 1.28.
Apparently, this analysis and scores reflect the users’ significant level of satisfaction with the effectiveness of the AMAC system, chiefly as the AMAC system detects and instantly notifies of the delays that occur in the construction site on a daily basis via emails and SMS. These notifications assist decision makers to take the appropriate decisions in a timely manner to prevent the delays and subsequent cost overruns.

8.3.5 AMAC system contribution to complete the case study project ahead of its planned schedule

The causes of delays are diverse and are unlikely to be controlled and prevented unless they are instantaneously detected. Ultimately, the AMAC system assisted the project team to detect the delays on a daily basis.
For example, some delays occurred due to the late procurement of blockworks which were supposed to be procured on site by ***1st March 2019*** at the latest to start the blockworks

activity, and therefore a notification email as shown in Figure 8.22 was sent on ***2nd March 2019*** to the concerned staff notifying them of a 7% delay.

Based on the incurred delays the AMAC system was designed to automatically calculate the expected slippage of the completion date for the project as ***19th April 2020*** instead of ***19th January 2020***.

Based on the AMAC system's notification email and SMS, the contractor was in immediate contact with the blockwork supplier, and accordingly, the procurement date for the blocks was amended as was the construction program to show the procurement date of blockworks as ***17th March 2019***, resulting in resources being reallocated. The delay was mitigated promptly and recovered the next day.

Figure 8.22: Email shows 7% delays detected instantly by AMAC system

In fact, all the interviewees (i.e. the system users) have emphasised that, the AMAC system supported decision-makers to obtain timely and accurate information, which assisted them to make the right decisions at the right time to address any potential project delays. They also reported that, the AMAC system is unique due to its unprecedented and distinctive automated features, particularly, the ability of sending notification emails and SMS' which kept the staff continuously alerted of any delays. According to the AMAC users, the system updated them on a daily basis with factual and reliable details of the progress status, which accordingly gave them optimal control on the project. And because of the effectiveness and prominence of the AMAC system in the case study at the substation, the project completed before the contract completion date with significant cost and time savings.

All aforementioned features were successfully tested in front of examiners during the researcher's 2019 progression exam in Bristol, UK for monitoring and updating the progress of the construction site in Dubai.

8.4 The second stage of empirical validation

This section involved comparison of the performance of the AMAC system against the conventional approach using performance records for 132/11 Kv electrical substations built in the previous 10 years (identical to the one used in the case study. DEWA records show that, DEWA built 48 substations between January 2010 and April 2020 as detailed in figure 8.23. The details such as the contract start, contract completion date, actual start, and actual completion date, in addition to, the original contract value and the actual value at completion, time delays and cost overruns were illustrated in Figure 8.23.

Clearly, the conventional approach that DEWA followed in the past 10 years was ineffective as evidenced with the 48 substation projects experiencing an average slippage of 6.7 months behind the original schedule. This represents a 30.21% delay in the projects in average contract duration and a 6.74% average cost increase against the original contract values.

Substation Name	Contract commencement date	Revised commencement date	Contract Completion date	Actual completion date	Contract duration	Delays (days)	% of delays	Contract value (AED)	Actual value (AED)	Additional cost (AED)	% of cost overrun
A	22/Dec/10	16/Jan/10	10/Jul/12	25/Jan/13	566	199.00	35.16%	65879555.00	70,425,244	4,545,689	6.45%
B	5/Jan/10	5/Jan/10	28/Aug/11	11/Feb/12	600	167.00	27.83%	64654560.00	68,145,906	3,491,346	5.12%
C	25/Feb/10	25/Feb/10	17/Nov/11	17/Jun/12	804	213.00	26.51%	60,666,123	65,398,081	4,731,958	7.24%
D	21/Mar/10	25/Mar/10	12/Oct/11	22/May/12	761	223.00	29.30%	64,985,510	69,521,499	4,535,989	6.52%
E	25/May/10	25/May/10	16/Dec/11	18/Jun/12	631	185.00	29.30%	66,564,890	70,825,043	4,260,153	6.02%
F	25/May/10	20/Jul/10	14/Feb/12	1/Sep/12	754	200.00	26.51%	76,550,250	81,832,217	5,281,967	6.45%
G	17/Jul/10	17/Jul/10	8/Jan/12	19/Jul/12	624	193.00	30.93%	61,980,450	65,575,316	3,594,866	5.48%
H	25/Aug/10	25/Aug/10	26/Mar/12	12/Nov/12	801	231.00	28.84%	63,542,120	68,816,116	5,273,996	7.66%
I	1/Oct/10	1/Oct/10	13/Apr/12	21/Oct/12	640	191.00	29.82%	66,120,550	69,823,301	3,702,751	5.30%
J	30/Nov/10	4/Dec/10	22/Jun/12	20/Oct/12	410	120.00	29.30%	63,215,450	66,313,007	3,097,557	4.67%
K	1/Mar/11	17/Mar/11	20/Nov/12	25/Jun/13	819	217.00	26.51%	66,666,000	71,199,288	4,533,288	6.37%
L	16/Apr/11	16/Apr/11	7/Oct/12	22/Apr/13	637	197.00	30.93%	64,560,560	68,498,754	3,938,194	5.75%
M	17/May/11	17/May/11	13/Dec/12	12/Jul/13	728	211.00	28.99%	63,215,250	68,209,255	4,994,005	7.32%
N	12/Jul/11	12/Jul/11	1/Apr/13	1/Sep/13	576	153.00	26.55%	67,666,600	71,320,596	3,653,996	5.12%
O	16/Sep/11	16/Sep/11	9/Mar/13	24/Sep/13	643	199.00	30.93%	69,120,000	72,852,480	3,732,480	5.12%
P	27/Nov/11	27/Nov/11	23/Jun/13	5/Feb/14	780	227.00	29.09%	71,180,452	78,156,136	6,975,684	8.93%
Q	15/Jan/12	15/Jan/12	7/Aug/13	1/Feb/14	608	178.00	29.30%	73,125,520	79,048,687	5,923,167	7.49%
R	14/Apr/12	17/Apr/12	21/Oct/13	30/May/14	734	221.00	30.09%	69,870,125	76,717,397	6,847,272	8.93%
S	16/Jul/12	16/Jul/12	15/Feb/14	4/Oct/14	801	231.00	28.84%	70,000,000	79,100,000	9,100,000	11.50%
T	15/Sep/12	15/Sep/12	23/May/14	5/Oct/14	497	135.00	27.15%	71,120,125	75,615,628	4,495,503	5.95%
U	1/Nov/12	1/Nov/12	28/Apr/14	7/Dec/14	725	223.00	30.76%	73,125,100	78,243,857	5,118,757	6.54%
V	1/Nov/12	17/Nov/12	10/May/14	11/Oct/14	512	154.00	30.09%	74,125,000	78,794,875	4,669,875	5.93%
W	17/Jan/13	17/Jan/13	8/Jul/14	7/Feb/15	688	214.00	31.10%	69,125,450	74,033,357	4,907,907	6.63%
X	1/Mar/13	1/Mar/13	23/Sep/14	8/Apr/15	674	197.00	29.25%	68,452,000	73,996,612	5,544,612	7.49%
Y	17/Mar/13	25/Apr/13	11/Jan/14	30/Aug/14	415	231.00	55.67%	72,120,000	77,745,360	5,625,360	7.24%
Z	21/May/13	21/May/13	29/Nov/14	5/May/15	524	157.00	29.98%	70,100,000	74,306,000	4,206,000	5.66%
A1	1/Jul/13	1/Jul/13	21/Feb/15	26/Sep/15	780	217.00	27.83%	73,500,000	78,865,500	5,365,500	6.80%
B1	15/Aug/13	15/Aug/13	3/Feb/15	2/Jul/15	479	149.00	31.10%	71,489,000	75,492,384	4,003,384	5.30%
C1	26/Sep/13	4/Oct/13	20/Apr/15	28/Nov/15	759	222.00	29.25%	68,158,125	73,815,249	5,657,124	7.66%
D1	12/Nov/13	12/Nov/13	10/May/15	10/Oct/15	498	153.00	30.70%	71,230,200	75,432,782	4,202,582	5.57%
E1	2/Feb/14	15/Feb/14	27/Jul/15	29/Mar/16	795	246.00	30.93%	71,222,000	77,560,758	6,338,758	8.17%
F1	15/May/14	15/May/14	17/Sep/15	17/Jan/16	358	122.00	34.08%	72,000,000	75,240,000	3,240,000	4.31%
G1	13/Feb/15	13/Feb/15	24/Aug/16	26/Apr/17	819	245.00	29.93%	73,163,500	80,187,196	7,023,696	8.76%
H1	18/Jun/15	18/Jun/15	11/Jan/17	19/Jul/17	648	189.00	29.14%	69,780,360	73,548,499	3,768,139	5.12%
I1	19/Jul/15	19/Jul/15	8/Feb/17	13/Sep/17	741	217.00	29.30%	71,230,125	76,786,075	5,555,950	7.24%
J1	7/Nov/15	7/Nov/15	30/May/17	26/Jan/18	823	241.00	29.30%	72,562,250	79,020,290	6,458,040	8.17%
K1	15/Feb/16	15/Feb/16	20/Aug/17	14/Feb/18	588	178.00	30.25%	70,890,500	75,427,492	4,536,992	6.02%
L1	16/Apr/16	28/May/16	7/Dec/17	28/Jul/18	837	233.00	27.83%	73,300,000	79,457,200	6,157,200	7.75%
M1	12/Oct/16	25/Oct/16	6/May/18	11/Nov/18	646	189.00	29.25%	71,298,600	75,505,217	4,206,617	5.57%
N1	12/Mar/17	12/Mar/17	22/Oct/18	27/Mar/19	550	156.00	28.35%	74,879,360	77,649,896	2,770,536	3.57%
O1	19/Jul/17	19/Jul/17	29/Nov/18	3/Sep/19	829	278.00	33.53%	72,780,900	81,514,608	8,733,708	10.71%
P1	2/Oct/17	23/Oct/17	14/May/19	16/Dec/19	762	216.00	28.35%	74,420,690	80,858,080	6,437,390	7.96%
Q1	27/Nov/17	27/Nov/17	21/Jun/19	25/Dec/19	639	187.00	29.25%	71,697,420	76,501,147	4,803,727	6.28%
R1	5/Jan/18	5/Jan/18	6/Aug/19	12/Mar/20	758	219.00	28.89%	72,987,500	79,483,388	6,495,888	8.17%
S1	16/Apr/18	16/Apr/18	10/Jul/19	6/Jan/20	485	180.00	37.11%	73688999	78,854,598	5,165,599	6.55%
T1	15/Mar/16	22/May/16	5/Dec/17	16/Jul/18	841	223.00	26.51%	75654889	81,775,370	6,120,481	7.48%
The case study	21/Dec/17	13/Dec/17	19/Jan/20	19/Nov/19	759	No delays	0.00%	72,589,850	72,589,850	0	0.00%

Figure 8.23: List of electrical substations in the last 10 years

However, the AMAC system succeeded in saving 61 calendar days which represents a 9.17% of the overall duration of the case study project with the project finishing on 19th November 2019 ahead of the planned 19th January 2020 as shown in Figure 8.24. Additionally, the AMAC system saved approximately AED 2,272,000 (≈£265,000) which equates to 3% of the contract value.

These savings were considered promising, particularly as 65% of the project budget was dedicated to the procurement of electrical and mechanical equipment and materials such as transformers, 132SWGR & 11kV SWGR panels, high voltage cables, etc. which were outside the scope of this research project.

In fact, the outlook for AMAC system is encouraging as it is expected to achieve or even exceed a 10% saving in time and cost, once it is formulated for universal use in and adopted by the whole construction industry as business-as-usual.

Figure 8.24: AMAC system Dashboard for the project at completion

8.5 Theoretical validation of AMAC system

Although empirical validation adds significant value and credence to the developed system, nevertheless, theoretical validity is essential predominantly as it adds weight to the validation process with its application in diverse operations and practices (Green and Glasgow, 2006). Furthermore, it ensures the developed system is valid for widespread use and it is not limited to use in the developed case study (Inagaki and Sheridan, 2012).

According to Green and Glasgow (2006) determining the level of accuracy is the predominant and most widely adopted measure for theoretical validation of a developed system-based software. Subsequently, the inferred accuracy is then compared with the findings of the published literature for similar systems.

ISO/IEC (2010, p.6) has defined accuracy as a "qualitative assessment of correctness or free from error and a quantitative measure of the degree of error. It is also defined as the closeness of the agreement between the result of a measurement and the true value of the measurand".

To determine the accuracy of a system such as AMAC, there are several methods employed for this purpose. However, the literature review expressed that the most widely adopted methods are **Mean Absolute Deviation (MAD**) and **Mean Absolute Percentage Error (MAPE)**.

However, the most widely used methods/formula is MAPE, specifically for software developed to fulfil specific purposes in the construction project management.

The literature survey shows that MAPE has been used by several researchers to gauge the accuracy of their developed systems (Xiao, 2002; Chen, 2007; Zhang *et al.,* 2017; *Jaber et al*., 2019; Nhu *et al.,* 2020).

MAPE was introduced by Conte *et al.,* (1985) and since then it is widely adopted in determining the accuracy of the developed software systems.

$$\text{MAPE} = \sum_{i=1}^{n} \left| \frac{(Est_i - Act_i)}{Act_i} \right| \times \frac{100\%}{n}$$

MAPE is a percentage value that is equal to the mean relative error. This is the arithmetic difference between the dimensions measured by the system subtracted from the actual measurements of the object, divided by the value of the actual measure.

$Est_i = estimated\ measure$ & $Act_i = Actual\ measure$

To determine the accuracy of the AMAC system, a number of measurements were taken and substituted into the above formula repeatedly on daily basis and the data recorded. Below is an example of the accuracy estimation for the R.C. column (vertical element) and slab (horizontal element).

Column (650×600 mm)

$$\frac{1}{5}\sum_{i=1}^{n} \left| \frac{(654-650)+(652-650)+(648-650)+(653-650)+(654-650)}{650+650+650+650+650} \right| \times 100\%$$

$$= \mathbf{0.09}\%$$

$$\frac{1}{5}\sum_{i=1}^{n} \left| \frac{(656-600)+(654-600)+(558-600)+(557-600)+(559-600)}{600+600+600+600+600} \right| \times 100\%$$

$$= \mathbf{0.10}\%$$

Slab (40×25 m)

$$\frac{1}{5}\sum_{i=1}^{n} \left| \frac{(40.03-40)+(40.06-40)+(39.97-40)+(40.04-40)+(40.04-40)}{40+40+40+40+40} \right| \times 100\% = \mathbf{0.02}\%$$

$$\frac{1}{5}\sum_{i=1}^{n} \left| \frac{(25.04-25)+(25.09-25)+(25.10-25)+(24.96-25)+(25.04-25)}{25+25+25+25+25} \right| \times 100\% = \mathbf{0.05}\%$$

Wall (8×0.25 m)

$$\frac{1}{5}\sum_{i=1}^{n} \left| \frac{(8.01-8)+(8.02-8)+(8.01-8)+(7.99-8)+(8.03-8)}{8+8+8+8+8} \right| \times 100\% = \mathbf{0.04}\%$$

$$\frac{1}{5}\sum_{i=1}^{n}\left|\frac{(25.05-25)+(25.03-25)+(25.05-25)+(24.97-25)+(25.03-25)}{25+25+25+25+25}\right|\times 100\% = \mathbf{0.03}\%$$

Beam (80×50 cm)

$$\frac{1}{5}\sum_{i=1}^{n}\left|\frac{(80.02-80)+(80.03-80)+(80.05-80)+(80.07-80)+(80.03-80)}{80+80+80+80+80}\right|\times 100\% = \mathbf{0.01}\%$$

$$\frac{1}{5}\sum_{i=1}^{n}\left|\frac{(50.03-50)+(50.05-50)+(50.05-50)+(50.07-50)+(50.04-50)}{50+50+50+50+50}\right|\times 100\% = \mathbf{0.02}\%$$

Raft foundation (50×40m)

$$\frac{1}{5}\sum_{i=1}^{n}\left|\frac{(50.01-50)+(50.02-50)+(49.97-50)+(50.03-50)+(50.04-50)}{50+50+50+50+50}\right|\times 100\% = \mathbf{0.01}\%$$

$$\frac{1}{5}\sum_{i=1}^{n}\left|\frac{(40.03-40)+(40.05-40)+(39.98-40)+(40.04-40)+(40.03-40)}{40+40+40+40+40}\right|\times 100\% = \mathbf{0.017}\%$$

Likewise, MAD is the calculated average difference between the dimensions measured by the AMAC system and the actual dimensions, expressed in the following formula.

$$\text{MAD} = \frac{1}{n}\sum_{i=1}^{n}(Est_i - Act_i)$$

Table 8.5: Accuracy calculation of the AMAC system

Construction element	MAD	MAPE
Column length 650mm	3mm	**99.91%**
Column width 600mm	3.2mm	**99.90%**
Slab length 40m	0.04m	**99.98%**
Slab width 25m	0.10m	**99.95%**
Wall length 8m	0.016m	**99.96%**
Wall width 25 cm	0.0375 cm	**99.97%**
Beam height 80 cm	0.04 cm	**99.99%**
Beam width 50cm	0.05 cm	**99.98%**
Raft foundation length 50m	0.025m	**99.99%**
Raft foundation width 40m	0.034 m	**99.98%**

The above accuracy values are credible, as they are supported by the various verification processes undertaken at the site throughout the progression of the construction project. Moreover, according to Agisoft PhotoScan (2017 p.47), the larger the size of the captured object the more superior the accuracy; this clear from the accuracy of the slab compared with the smaller dimensions of the columns.

Additionally, due to the high levels of accuracy for the system and the authentic information offered to the decision makers throughout the real-life of the case study, the AMAC system succeeded in assisting the decision makers to take timely and appropriate actions to complete the project ahead of its original completion date.

Table 8.5 explicitly demonstrates the notable high levels of accuracy from the AMAC system.

8.5.1 The effectiveness and accuracy of the AMAC system

The case study revealed that the whole process, starting from capturing the photos until the point of sending notification emails and SMS' takes less than 3 hours. The accuracy of the system was studied and reported from two perspectives as follows:

- the first perspective concerns the ***"physical correctness"*** of the reported information, to ensure an accurate reflection of the activities included within the 4D viewer screen. This type of accuracy was considered a significant concern, primarily as these type of inaccuracies tend to reoccur due to human error when employing conventional manual approach.

  For example, the contractor already built 20 R.C. columns; however, the manual updates show details for only 19 columns with the twentieth column missing due to human subjectivity, incorrect counting and likewise. Consequently, these types of mistakes end up affecting the detail in the final report will mislead the project manager due to various missing activities (Ibrahim *et al.,* 2009; Dimitrov and Golparvar-Fard, 2014; Omar *et al.,* 2018).

  The ***"physical correctness"*** was thoroughly checked on many occasions throughout the case study to verify the notifications and the updates displayed in the AMAC "Dashboard" and "4D viewer" and therefore to ensure confidence in and reliability of the progress updates for the reported activities.

  Ultimately, the iterative verifications revealed that the AMAC system confidently did not overlook any site activities throughout the lifetime of the case study. This is primarily as the 12 cameras were designed to cover all the details of the construction activities throughout the whole site, during the different stages of construction progression and accordingly everything the cameras capture is processed and reported automatically. This is in addition to the predefined rules and logic put forward to ensure that no construction activity was overlooked.

- The second perspective concerned the "***correctness of the percentage***" of the progress status, which was automatically calculated by comparing the point cloud model against the BIM model.

  At the beginning of the project, it was mutually agreed with the Project Manager of the contractor not to share the reports from the AMAC system with the survey staff, to allow for several comparisons between the manual reports developed by the traditional method and the results reported by AMAC.

  Subsequently, and after a series of thorough reviews of randomly selected elements on various days throughout the project life, the recorded error for the horizontal dimensions was 1 mm, which means that a horizontal accuracy of 99.97% was achieved.

  Similarly, the recorded error for the vertical dimensions was 3 mm for every 1 linear meter, resulting in a vertical accuracy of 99.70%. And, the accuracy for the areas and volumes were 99.60% and 99.75% respectively, and 100% accuracy was achieved for quantified numbers.

These accuracies were collectively determined based on the reports developed automatically by the AMAC system over the lifetime of the case study which slightly differs from the accuracy in

Table 8.5, mainly because the table illustrates several measures for only two elements. However, the collectively determined accuracy for the AMAC system is for the whole project which were repeated on numerous occasions to determine precisely the system's accuracy.

Details of the accuracy obtained from the case study that represents the accuracy of AMAC system are shown in Table 8.6.

Table 8.6: Accuracy of AMAC system

Quantification	MAD Error(mm)	MAPE Average Accuracy %
Raft foundation, Beam and slab	1 mm/1m	99.98%
Wall	1 mm/1m	99.97%
Column	3 mm/1m	99.70%
Area	0 $mm^2/1m^2$	99.60%
Volume	6 $mm^3/1m^3$	99.75%
Quantified number	0	100%
The overall accuracy of the system	1.5mm/1m	99.85%

8.5.2 Comparing the accuracy of AMAC system against other similar systems

The results in Table 8.6 are momentous and suggest that the AMAC system has delivered a step change in improving the monitoring, analysing, updating, and control of construction site activities.

Accordingly, the proposed system deemed outstanding due the achieved accuracy, reported in Table 8.6, and is far superior than any other proposed system to date, wherein Dimitrov and Golparvar-Fard (2014) only achieved 100% accuracy for three suboptimal construction elements (i.e. formwork, grass and marble).

Table 8.7 demonstrates the high level of accuracy achieved by the AMAC system in comparison to historic and currently available systems.

Table 8.7: Accuracy of AMAC system in comparison to other systems

		Dick *et al.*, (2004)	**Dimitrov and Golparvar-Fard (2014)**	**AMAC system**
Automation		Partially automated	Partially automated	Fully automated
Used Technology		Framework acquisition algorithm and photogrammetry	Machine Learning classifier, point cloud and photogrammetry	Photogrammetry, BIM and point cloud
Accuracy for construction elements	Raft foundation	83%	92.1%	99.98%
	Slab	83%	92.1%	99.98%
	Beam	83%	92.1%	99.98%
	Wall	91%	92.1%	99.97%
	Column	91%	92.1%	99.70%
	Quantity	×	×	100%
	Area	×	×	99.60%
	Volume	×	×	99.75%

Practically, the AMAC system is fully automated and does not require any expertise to operate. The findings reveal that AMAC system is original and could significantly improve construction site monitoring and controlling.

The cost of AMAC system was a concern to interviewees from both the focus group and the face-to-face interviews and as such the following section presents the cost of the system.

8.5.3 The cost of AMAC system

The used hardware and software in this case study cost ≈ £41,400 (forty-one thousand and four hundred pounds), bearing in mind that purchasing the server was a considerable cost. The hardware and software can be used several times. Moreover, the capacity of the server can accommodate up to 20 projects at the same time, which will markedly reduce the cost of forthcoming projects.

In fact, the actual cost for upcoming projects will be virtually be zero in the case where the hardware and software can be reused. The cost of the cameras, routers and the Wi-Fi extenders equate to approximately £1000 (one thousand pounds) for each camera including its ancillary products.

It is clear that the system is very cost effective and is affordable for any project size, even small size projects.

The development of AMAC system was built on an internet network and with browsing features, and accordingly, securing the information was one of the paramount concerns. Thus, the following section discusses and details the plan that has ensured security of the information.

8.6 Information security plan

Since the system employs software, hardware and sharing of information via a browser, it is essential to consider potential information security issues. Therefore, the project's information security system was customised and designed specifically for this project in line with the case study owner's information security regulation's version 2 and in line with (El-Hadary and El-Kassas, 2014). The system was designed to protect against disclosure of sensitive data to unauthorised individuals. Additionally, high measures of control were considered to ensure confidentiality when the data is at *Rest, Transit and Processing*. The system's functionality and accuracy are ensured by the system modelling analysis to ensure the data can only be modified by an authorised person using an authorised process. Moreover, the system was designed to ensure that handled data is complete and there is consistent implementation of security controls like hashing and encryption. The system ensures its legitimacy and validity, and also defines permissions to be assigned to all authenticated users and building an audit trail of all users actions, for example, when unauthorised users make a change, or when an authorised user makes an unauthorised change. In the case study, the local server was used as the owner does not allow the use of cloud servers, due to concerns about cyber security issues. The system was designed with full compliance to DEWA Information Security Regulations (ISR) Version 2.

The front set goals

- Identify the project's potential security risks.
- Analyse and prioritise identified project security risks.
- Develop a risk mitigation plan to alleviate and/or eradicate project security risks.

- Ensure the continuous monitoring of project security risks for the whole duration of the project.
- Communicate the risk mitigation plan and any foreseen risks to the DEWA cyber security team.

8.6.1 Information security methodology

The methodology is based on the problem frame concept whereby the problem frame sets out potential software development problems. This concept helps to analyse problems that need to be solved and where there are interactions between software and domains exist within a system environment. The problem frame concept was used to break down the system's context into simpler and smaller problem chunks which are well-known problem classes and are easier to deal with. The methodology aims to identify security requirements with the help of previous security knowledge by constructing a security catalogue for this purpose. The security catalogue consists of problem frame models for threats and the corresponding security requirements. Threats are modelled using abuse frames whilst security requirements are modelled using the security problem frame. The following Figure 8.25 illustrates the steps of the information security plan for the proposed system.

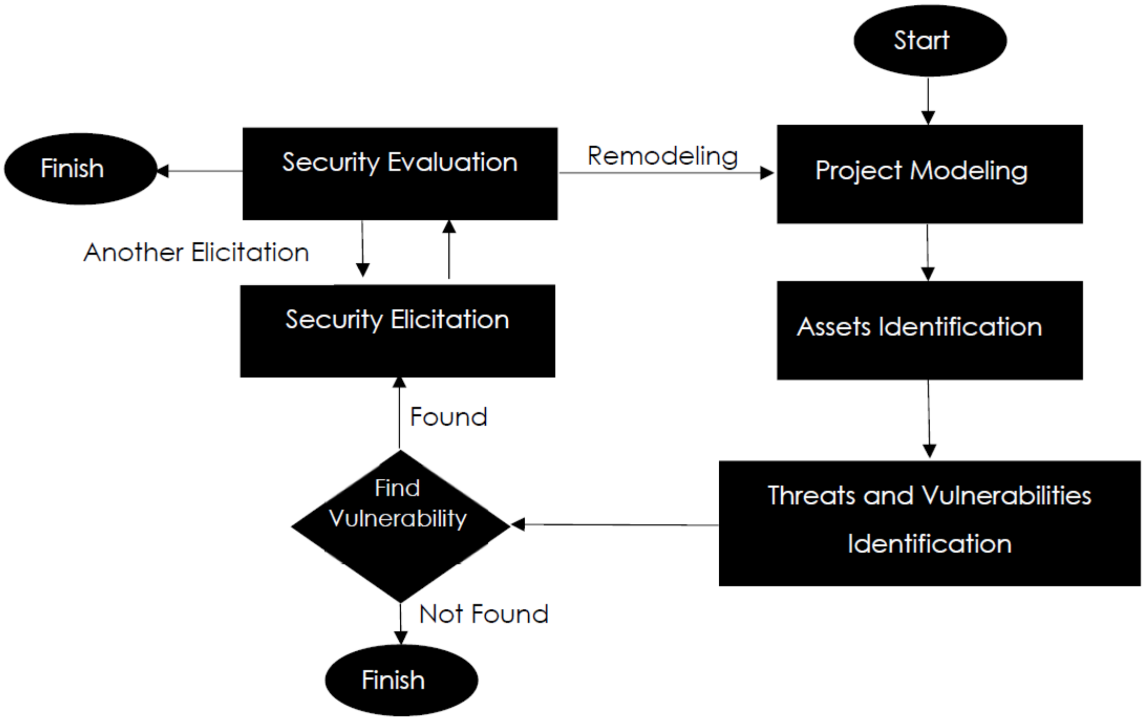


Figure 8.25: Information Security Requirement Methodology Diagram

The following Table 8.8 demonstrates the information security compliance plan

Table 8.8: Information security compliance plan

	Feature	Compliance status		Remarks
		Comply	Doesn't comply	
1	Reducing the project security risk by putting all vulnerable and non-vulnerable data on the local site server. And, only use the analysis result for monitoring and notification by the main project application server.	√		Reference made to DEWA ISR Ver.2 Sections 5.26 A, 6.3, 6.4, 6.5, 6.6 and 6.7
2	All vulnerability data should not leave the premises of the Case Study owner.	√		
3	The project is independent (All data and engines are located on the site server) and does not connect to any other network.	√		
4	Captured construction site images should have end-to-end Encryption	√		Binary serialised and compressed. reference made to DEWA ISR Ver.2 Sections 5.26 A and 6.6.6
5	User registration and deregistration and users' access modification privileges are disabled and removed	√		Reference to DEWA ISR Ver.2 Sections 5.2
6	Used an authentication technique to validate of the identities of users	√		Reference to DEWA ISR Ver.2 Sections 5.2

8.7 Summary of the Chapter

The first section of this chapter has exhibited all the features of the AMAC system which are deemed to be predominant attributes of the system. To ensure a successful outcome of the system, it has been extensively tested and validated after rolling it out in a real-life full cycle case study.

The second section introduced the empirical validation of the system, by collecting feedback via an online survey from 40 users of the AMAC system, on the performance and effectiveness of the system. The collected and analysed data offered rigorous evidence on the users' significant satisfaction of the AMAC system compared to the conventional approach. After testing the effectiveness of the AMAC system, the users of the system strongly recommended, that it be rolled out for use throughout the construction industry, to allow better control of construction projects and reduce time delays and cost overruns.

Additionally, a longitudinal comparison of the performance of 48 research projects over the last 10 years and similar to the case study, revealed the superiority of the AMAC system against the conventional approach used for detecting and notifying delays.

Additionally, theoretical validation of AMAC system sought to determine the accuracy of the AMAC system and then compare it against some of the leading research publications on similar systems. Ultimately, the AMAC system proved itself as a robust, efficient and effective system; cost effective, accurate, reliable, easy to use and a fully automated system developed that can instantly detect and notify delays in construction projects.

Chapter 9- Conclusion Post-Development stage

9.0 Introduction

This chapter provides a conclusion to this research in its entirety in line with the methodology and key findings. This concluding chapter discusses at a strategic level, the research objectives, key findings of the research study, contribution to the knowledge within this area and recommendations for the construction industry, policy makers and for further research.

9.1 Review of research objectives

Almost all construction projects tend to suffer from time and cost overruns; wherein 98% of projects experience an average slippage of 20 months beyond their original schedule with an average cost increase of 80% on original value. These overruns are associated with a failure to deal with a lack of control within construction projects, which are often brought about by poor project management strategies and outdated technologies that failed to instantly detect delays.

Additionally, the conservative nature of the construction industry tends to hold on to ineffective monitoring and management systems, which has adverse implications in the speed and robustness of decision making.

The literature review in addition to the primary data collection from construction professionals presented concrete evidences that, the prevailing systems that sought to detect delays tend to suffer from various inefficiencies, which resulted in failure to detect and report potential delays. In addition, they do not have the ability to collect accurate data to reflect the correct as-built site progress status.

This research in addition to the literature study revealed that, despite recent technological advancements worldwide, the existing monitoring and management systems used in the construction industry are still dominated by traditional approaches, including manual paper-based collection and recording of on-site activities.

The manual approach is often cumbersome, as site managers and inspectors manually collect and record progress of construction site activities, and then re-enter the collected records and interpret them at the site office. Moreover, this process is extremely slow as it is laborious, tedious and the inspectors spend approximately quarter of their daily duties updating the progress status.

Moreover, the manual approach based-delays detection has several limitations, resulting in missing, incomplete, or incorrect information. Inevitably, site teams and decision makers are usually furnished with unreliable and unauthenticated progress details. Consequently, the information presented to decision makers tends to lead to confusion with a high probability of questionable decisions being made, which has repercussions for the effective allocation of resources.

The literature review provided an example, whereby decision makers judged an activity as suffering from delays based on information derived from using the manual progress monitoring report, wherein reality the project was significantly ahead of schedules. In this case, the decision makers believed that the construction project was delayed, even though it was proceeding ahead of the planned schedule. Consequently, extra resources were deployed to that activity resulting in a waste of time and money.

This demonstrates that the current systems sought to detect delays are often unreliable, time-consuming, costly, and prone to subjectivity and errors. This gap in knowledge was recognised by several researchers who have attempted to develop semi-automated and automated systems to monitor and control construction site activities. However, the literature explicitly illustrates that all the proposed systems suffer from limitations and challenges that diminish their efficiency. Moreover, these systems lack the ability to instantaneously detect and notify the delays.

Ultimately, a reliable monitoring system that notifies the site team of delays immediately after they have occurred has not yet been realised; this gap in knowledge has persisted for many decades. Consequently, a rigorous and reliable monitoring system is needed to detect project delays, as soon as they occur to enable decision makers to manage the source of the delay and as such, reduce or eliminate the delay.

To that end, this study sought to develop a fully automated system to detect project delays and deliver timely and accurate information about any detected delays to decision-makers, to enable them to address any potential project delays. To achieve the aim of this study, the following five objectives were developed:

Objective 1: "*critical review and identification of requirements and needs through a review of literature as well as state-of-the-art on automated progress monitoring systems*".

To achieve this objective, an extensive study of the existing literature investigation was conducted to acquire an in depth knowledge and understanding of the current state-of-the-art systems, used for monitoring and updating construction activities; with a special focus on the technology employed and the advantages and limitations for each initiative.

This objective was introduced in Chapters 2 and 3, whereas, the literature study in Chapter 2 offered rigorous evidence that time delays remain one of the most formidable and persistent problems for the construction industry worldwide. Whilst Chapter 3, introduced and analysed in depth, the existing systems and approaches utilised to detect and report delays in construction projects.

However, the literature study revealed that to date, there is no approach or system that has been developed to successfully automate the monitoring, analysing and control process of construction site activities, to instantly detect any delays once they have occurred. Ultimately, the literature study offered rigorous evidence of the astounding inability of all the proposed systems to instantly detect delays in construction projects.

Accordingly, this gap in knowledge warrants further investigations and additional efforts to find an automated system that can promptly detect delays once they have occurred at the construction sites, and as a result send automatic notifications to the decision makers.

Objective 2: *"contextualise a hypothetical approach as an alternative and effective solution for automated construction progress monitoring"*.

The extensive knowledge gained from the literature study enabled a deeper understanding of the limitations and strengths of the existing systems including those currently employed technologies. The literature revealed that some of the proposed systems which integrated two or more technologies succeeded, to a certain extent to automate the monitoring and control of construction site activities.

Accordingly, existing technologies such as BIM, and specifically its ease of integration and synchronisation with computer vision and 3D point cloud models, were exploited to automatically compare as-planned schedule against as-built status, enabling accurate and reliable identification of project overruns.

The methodology for developing a pioneering system was extensively investigated, and the outstanding results of several similar research studies were promoted, mainly as they followed the design science approach. The details of the adopted research methodology introduced in Chapter 4.

In fact, the design science approach formed the basis of this research and was followed step-by-step, for the effective development of the system. This approach materialised at the pre-development stage which involved data collection from secondary sources, that is already published research, and a primary source via a focus group. The focus group was conducted with carefully selected professionals who have practical experience in construction projects combined with robust in-depth knowledge of delays in construction. They were asked open-ended questions to evaluate the components and features of the proposed system, that derived from an analysis of state-of-the-art systems in the development of approaches, tools and techniques for the detection and notification of project overrun. Participants' responses were analysed using NVivo software. **The output** was "*an informed-basis for the development of an automated system for detecting and notifying delays in construction projects*", these details were addressed in chapters 5 and 6.

Objective 3: "*prototyping incrementally an automated system for construction progress monitoring by integrating photogrammetry, computer vision and Building Information Modelling (BIM)".*

In line with the design science approach, this stage involved the development, testing and verification of a proof of the concept for the proposed prototype of an automated system to detect delays and send timely automated notifications to support decision-makers. Participants of this stage consisted of 9 users of the system representing a sample of contractors, consultants, and owners. They were asked open-ended questions via face-to-face interviews, to evaluate and verify the effectiveness of the developed prototype. The prototype was continuously refined and improved according to the users' comments and feedback. **The output** was "a *prototype that is tested and evaluated by a representative sample of construction professionals*", and these details are addressed in chapter 7.

Objective 4: *"test the prototype system in practice to validate the novelty of the proposed approach for automating monitoring the progress in construction projects in order to detect the delays".*

This stage sought to test and validate the final version of the AMAC system in the context of real-life construction site in Dubai. This validation allowed a comprehensive comparison of the effectiveness of the developed system in comparison to conventional monitoring and notification approaches. To that end, an online survey using Qualtrics was administered to a representative sample of the system's end-users to assess the effectiveness of the system. The collected data from 40 end-users, an equal mix of contractors, sub-contractors, consultants and owners, was statistically analysed using SPSS. **The output** was a "*developed system for the identification and notification of delays within the construction industry"*, with the details of this stage addressed in chapter 8.

Objective 5: "*evaluate the theorised approach of the system to develop recommendation for future research and practice*".

In accordance with that last process in design science, the researcher should disseminate their research conclusion to assist others and with these research findings encourage further studies and developments by other researchers. This research study offers some recommendations that have arisen from the findings and limitations of the research which are addressed hereinafter.

9.2 Reporting the key research findings

The research findings of this study offered concrete evidences on the effectiveness of developed system for instant detection and notifications of the delays in construction projects. The key findings of the research are summarised as follow.

- This research reveals that the performance records for all projects identical to the case study over the past 10 years, suffered an average of more than 30% time delays and more than 6.5% cost overrun.
  However, the AMAC system utilised in the case study has resulted in the construction project being completed ahead of schedule equating to a 9% time and 3% cost saving, which is unprecedented.
- The research demonstrates that all of the processes employed by the the AMAC system are automated; starting from data collection up to and including sending out the daily notifications via email and SMS, which informs the decision-makers about any occurred delay.
- The research findings highlight that the AMAC system successfully and instantaneously detects any discrepancies between the as-planned schedule and as-built status, which is again unprecedented in providing various stakeholders with accurate and timely notifications.
- The study findings also reveal that, AMAC system achieved exceptional accuracy, whereby, the system achieved 99.98% accuracy for raft foundation, slabs and beams, and 99.97% for walls, whilst the accuracy of 99.70% achieved for the columns. And 100% accuracy achieved for quantification, and the automatically calculated accuracy for areas and volumes are 99.60% and 99.75% respectively. Hitherto the accuracy of the AMAC system is unrivalled in terms of accuracy up against any of the current systems seeking to automate monitoring and detecting delays in the construction industry.

- The findings established that the AMAC system supports decision-makers to take appropriate decisions in a timely manner, based on authoritative information.
- The findings show that the AMAC system is accessible remotely as it is web-based, which allows the authorised users to access the system from any device such as computer desktop, smart phone, IPAD or tablet to monitor the progress status and recognise the delays at any time and from anywhere.
- The findings of the AMAC system illustrate that the causes of delays can be easily identified by checking the 4D viewer feature of AMAC system.
- AMAC is a fully automated system which shares the progress status details in an open environment, this openness boosts the transparency amongst the project stakeholders.
- The findings show that the cost of operating the AMAC system to operate is approximately £41,000 which makes it very economical and accordingly affordable to any project including small size projects. In fact, the cost of the AMAC system represented just 0.2% of the overall project cost of the case study; whilst the AMAC system made a 3% cost saving and a 9% time saving coming in ahead of schedule.
- The findings of the comparative study show that compared to other systems, in particular the conventional approach that dominates the construction industry; the AMAC system is easy to use, hassle free, easy to learn, and meets the users' expectations. Additionally, the AMAC system offers clear information, which is easy to interpret and assisted users to accomplish their tasks and prevent delays in the project.
- Interestingly, 100% of the users of AMAC system are satisfied with the effectiveness of the system which enabled them for the first time to complete the project ahead of its contractual completion date with significant cost and time savings and accordingly less disputes and a much improved reputation.

9.3 Contribution to knowledge

The case study provides empirical and rigorous evidences of the originality of AMAC as an effective automated system for monitoring, analysing, updating and notifying of the delays and progress status to decision-makers on a daily basis. Prior to the development of the AMAC system, several systems sought to automate progress updates for construction projects; however these systems suffer from various limitations that failed to detect potential delays. In addition, they did not have the capability to collect accurate data to reflect the correct as-built site progress status.

AMAC's distinguishing features include its low cost to operate, accuracy, instantaneous detection and notification of delays, daily notifications via SMS and emails and ease of use. All AMAC's features were tested, evaluated, verified and validated within two case studies with a sample of experts representing the various specialists within the construction industry.

Finally, the users of the AMAC system strongly recommended for the imperative utilisation of AMAC for all the forthcoming projects.

The main contributions of the AMAC system are summarised hereinafter.

- The findings of the study indicate that the AMAC system rescinds the sovereignty of the contractor in providing progress updates; the progress status is automatically updated and shared within an open environment, which accordingly, fosters the transparency and trust amongst all the project stakeholders.
- The study establishes that the AMAC system has followed empirical and robust development methods, including stringent verification and validation. Whereas, the research adopted the design science approach that has guided the cognitive development of the system correctly and astutely which has resulted in development of an innovative and original system that outrivals all the current systems.
- The research offers robust evidence that utilising the AMAC system as the mainstay project management tool for the instant detection and notification of delays, enables the project team to diligently control and prevent delays in the project. Whereas, the automated nature of AMAC system for data collection, processing, reporting and notifying the delays saves the site inspectors' time which was estimated as 20-30% of their daily duty time when using current systems (Gloparvar-Fard *et al.,* 2011; Solihin and Eastman, 2015). The time saved now enables the inspectors to conduct other tasks and accordingly, the contractor's productivity has improved which again has resulted in cost and time savings.
  Finally, the client's satisfaction has immensely increased and accordingly, the status of the contractor's image has been elevated.
- Above all, experience of the users of the AMAC system show that the system is easy to use as it is based on straightforward and swift navigation of the project details using only three screens.
  The first screen illustrates the overall progress status in the format of bar and pie charts, which shows the planned progress verses actual progress and shows the variances, and additionally, the key activities that cause the delays are shown.

The second screen displays all the delays and illustrates the status for each construction element as bar and pie charts as well, which shows the planned progress verses the actual progress and illustrates the variances for each element.

The third screen allows instant accessibility to the cameras to watch a live-stream view for the construction site to verify the level of adherence for the safety measures on site and to check the ongoing activities remotely. Thanks to this feature, the owner and consultant remarkably reduced their numbers of site visits.

9.4 Limitations of the study

Although the users of both case studies have emphatically welcomed and strongly recommended utilising the AMAC system for all forthcoming construction projects the system has few areas that need to be addressed as discussed below:

- The system in its entirely is powered by an electrical power supply, for which the server has a backup UPS battery which ensures the continuity of the servers' capabilities for approximately two hours. However, the cameras do not have the same facility to ensure their functionality during electrical shutdowns; however, future developments in photogrammetry could address this issue.
- Although, an unplanned electrical outage did not occur during either of the two case studies, a planned experimental shut down of power was performed to check the system's performance in the case of electrical disruption. Consequently, it was found that the electrical disruption mandates human intervention to refresh the cameras; this is only required when the electric disruption happens during the process of capturing site photos.
- Calibration of cameras is highly recommended every year to ensure the highest accuracy achievable; calibration involves a planar checkerboard as mentioned in chapter 7 section 7.1.6.
- Although the system was only tested on civil construction elements i.e. the RC columns, beams, slabs, foundations, walls; the accuracy and performance of the system for the remainder of the project elements, including finishing and interior works, warrant further investigation.
- The system has been tested on a building project; however, longitudinal projects such as roadworks, tunnels, railways and pipelines warrant further investigation and in particular for data collection, which entails the use of different approaches for data collection such as a drone equipped with a camera.

- The AMAC system was tested in two case studies for construction buildings with a maximum height of 18.5 metres; however, technical designs and calculations determine that the system will work unreservedly for buildings up to 50 metres. However, buildings with a height exceeding 50 metres warrants further investigation.
- This research assumed all construction elements can be implemented according to the BIM model only.
- Finally, the system has been tested on outdoor construction activities only.

9.5 Conclusion

The study revealed that a reliable monitoring system that allows for the instantaneous detection and notification of delays to decision makers once occurred, has not yet been realised; with the gap in knowledge within this domain persisting. Consequently, a rigorous and reliable monitoring system is needed to detect project delays, as soon as they occur, to deal with source and therefore reduce or eliminate them.

Accordingly, this study sought to develop an automated close-range photogrammetry-based approach for monitoring and controlling construction site activities. The testing, verification, and validation of the developed system within two case studies offered concrete evidence that the AMAC system is an innovative and exceedingly reliable state-of-the-art system to automatically monitor, analyse, update and notify the progress status to the decision-makers.

In particular, the system succeeded in instantly detecting any discrepancies between the as-planned schedule and actual as-built status to provide the various stakeholders with accurate and timely feedback. This will support decision-makers in making appropriate decisions in timely manner based on the authoritative data alongside extraordinary accuracy; the proposed system achieved an overall accuracy of 99.85%.

Once cameras are installed and programmed, the system does not require any expertise or manual intervention. Above all, the system is easy to use and is cheap to operate, moreover, the progress status can be obtained anytime and anywhere.

9.6 Recommendations

The findings of this research and the conclusion suggest the following recommendations to obtain the maximum benefit of the AMAC system.

9.6.1 Recommendations for Industry

There is an urgent need to create a paradigm-shift in the construction industry, to convert its historical status of financial losses to profits. This could be accomplished by preventing delays in construction, and accordingly the causes of disputes will be reduced or eliminated, which will improve construction productivity.

- The findings of the full lifecycle case study at the 132/11 Kv substation offered concrete evidence that the adoption of an efficient automated system such as the AMAC allows instant detection and notification of delays.
  According to performance records from the last 10 years for projects identical to the case study, the 48 projects suffered from an average delay of 30.21% on the projects' average contract duration and an average cost increase of 6.74% of the average original contract value.
  However, adoption of the AMAC system enabled a significant time saving of 9% and 3% on cost, and for the first time in the past 10 years, the project was completed ahead of its original completion date.

- The findings of this research study demonstrated that the AMAC system is unlike any other system, wherein once the cameras are installed and programmed, the system does not require any further expertise or manual intervention. This is primarily as the system is fully automated - data collection, interpretation, analysis and notifications are all automatically processed without any need for human intervention.

- The findings established that the preeminent and distinctive feature of the AMAC system is that it is fully automated; this feature is not found in any other of the current systems or approaches. Accordingly, the automated nature of the system has resulted in eliminating human error and subjectivity. As a consequence of this absence of subjectively and therefore bias, alongside the system's significant accuracy and reliability, claims and disputed have significantly reduced and reputations repaired.
- The nature of the automation of the AMAC system makes it extraordinarily fast in detecting and notifying delays; the entire process from data collection to sending the automatic notifications via email and SMS for reporting the delays requires less than 3 hours. Whilst, the conventional approaches, that still dominate the construction industry, require a week or more to develop reports that are proven to be less accurate and less reliable.

- The findings from the two case studies elucidated that the system is easy to use, cost-effective which makes it affordable to any project including the small size projects.

9.6.2 Recommendations for Policy makers

The construction industry is plagued with poor performance and low productivity which has resulted from an absence of instant detection of delays. This predicament warrants immediate action to be taken from governments and decision-makers within the construction industry.

- The findings of this research underlines the effectiveness and success of the AMAC system to mitigate and stop delays in construction projects. However, the conservative nature of the construction industry hampers advancements and subsequently the adoption of new technologies. To that end, improving the performance in the construction industry necessitates imperative decisions to be taken by the governments and the construction industry decision makers to mandate technologies such as AMAC. Whereby, instant detection of delays allows the project team to mitigate or recover the delays immediately, ensuring the appropriate allocation of resources based on authoritative information.

- The findings show that by adopting the AMAC system contributes to significant cost and time savings in construction projects. Accordingly, this should motivate developers and/or governments to exploit these savings when launching additional projects to expedite the national development agenda for economic growth.

- Additionally, the AMAC system proved its efficiency in reducing disputes and claims, which accordingly saves time and the efforts of the project staff in carrying out additional tasks. Likewise, the human resources required to prepare manual reports for progress status updates, involves manual data collection, analysis and preparation are saved, enabling them to carry out other, more productive tasks. Accordingly, the AMAC system has made a significant contribution to increasing the rate of productivity within the construction industry.
- Above all, the findings of the case study offer rigorous evidence that the AMAC system succeeded in instantly detecting and reporting delays which enabled the decision makers to foresee the potential delays and act on them. Attributable to the

instant detection and notification of delays, decision makers have better control and management of the site which leads to better resource planning and allocation. This ultimately enabled the site team to improve rate of productivity and performance to realise an unprecedented accomplishment, completing the project with significant savings in terms of cost and time.

- The conservative nature of the construction industry obstructs advancements and adoption of new technologies such as the AMAC. Therefore, it is recommended that a supreme council is formed and funded by the key players in the construction industry and represents all the disciplines within the construction industry. The purpose of this supreme council should be to lead the construction industry towards investment and adoption of new technologies such as the AMAC, and its decisions should be binding for all the main players in construction industry.

9.6.3 Recommendations for Future research

Based on the reported limitations of this research, there is opportunity for those limitations to be addressed by future research as summarised below:

AMAC is a static system and accordingly, the system was developed to acquire essentially outdoor construction elements. However, the system could be further developed in any future research, to integrate data collection for both outdoor and indoor construction elements; following the testing of other methods to collect data for indoor construction elements. In this context, future research could investigate integrating the data collection of the interior works with the AMAC system through cameras mounted on the site supervisors' helmets and find a way for automatically forwarding the captured images to the AMAC system. This is the only required changed for the inclusion of indoor construction activities as all other processes within the AMAC system will remain the same for both indoor and outdoor construction elements.

- The available case studies for this research were only building projects, as such the AMAC system has been tested on building projects only. Thus, longitudinal projects such as roadways, railways, tunnels, pipelines and the like warrants the substitution of cameras for UAV/drones for data collection. However, similarly the rest of AMAC's system processes and automation can remain unchanged.
- The owner of the case studies had a conservative attitude towards the use of cloud severs, and therefore, the AMAC system used a local server as described in chapter 7. However, future research could be repeated using cloud servers to enable the faster processing of data calculations and it is expected to significantly reduce the

processing time from 3 hours to few minutes. In addition, there would be a significant cost saving.

- Future study could investigate synchronising the project costs from 5D BIM into the AMAC system to monitor and control project costs, by comparing the actual costs against the planned expenditures. Furthermore, adding in costs will enable automated development of the authentic monthly interim payment for the contractor in no time.

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Appendices

Appendix 1: Consent forms

Consent Form

Towards an automated photogrammetry-based approach for monitoring and controlling construction site activities

This consent form is to gain your approval to be involved in an online interview, designed to gauge your experience of determining the effectiveness of the automated system developed during this study for the detection of delays in construction projects to support project management decisions.

Please ensure that you have read and understood the information contained in the Participant Information Sheet and asked any questions before you sign this form. If you have any questions please contact a member of the research team, whose details are set out on the Participant Information Sheet.

Please check this link to recognise the rules of UWE privacy notice

https://www1.uwe.ac.uk/about/corporateinformation/datamanagement/privacynotices.aspx

If you are happy to take part in the online interview, please sign and date the form. You will be given a copy to keep for your records.

- I have read and understood the information in the Participant Information Sheet which I have been given to read before asked to sign this form;
- I have been given the opportunity to ask questions about the study;
- I have had my questions answered satisfactorily by the research team;
- I agree that anonymised quotes may be used in the final report of this study;
- I understand that my participation is voluntary and that I am free to withdraw at any time until the data has been anonymised, without giving a reason;
- I agree to take part in the research

Name (Printed)…………………………………………………………………….

Signature…………………………………………………. Date…………………….

Appendix 2:

Sample of general online survey to select participants of focus group

Dear Participant,

This survey is being conducted as part of a PhD study on delays detection in construction projects. The survey aims to select the participants of a focus group discussion to discuss the approaches and methods of how to stop delays in construction industry.

The survey will take 5-10 minutes. I would appreciate your participation.

All the collected data will be anonymously analysed. Participants will not be identified throughout this study.

Please read the attached information sheet to recognise all your reserved rights. At any time if you have any queries please, do not hesitate to contact the undersigned researcher.

Please return or direct any enquiries to:

Hany Omar |Doctoral Researcher |University of the West of England | Bristol, UK | Email: hany2.omar@live.uwe.ac.uk

Survey Instructions

- *Please answer all the following **six** question to the best of your knowledge and experience*

1. Which of the following best describes you?
   ☐Owner/Client ☐Contractor/subcontractor ☐Consultant (Design) ☐Consultant (supervision) ☐BIM specialist/Manager ☐Software programmer
   ☐Others *(Please Specify)*Click or tap here to enter text.
2. Please specify the overall number of years in the construction industry:
   ☐Less than 5 years ☐5-10 years ☐11-20 years ☐More than 20 years
3. Please state the number of years of experience in construction sector in Dubai:

   ☐Less than 2 years ☐2-5 years ☐6-10 years ☐More than 10

4. Have you ever suffered from delays in any of your previous or current construction projects?
   ☐ Yes ☐ No
5. How many causes you can estimate for the delays in construction projects?
   ☐Less than 2 ☐ 2-5 years ☐ 6-10 years ☐ More than 10

6. I can propose solution to stop or mitigate delays in construction projects.
   ☐ Yes ☐ No

If you agree to participant in the focus group interview, please furnish the following details

Mobile number: Email address:

Appendix 3:

Sample Invitation Letters and Information Sheets

Construction and Property Research Centre

University of the West of England

Bristol

BS16 1QY

United Kingdom

Date…/…/ 2019

Dear Sir/Madame,

REQUEST FOR PARTICIPATION IN RESEARCH ON automated system for monitoring and controlling construction site activities

The University of the West of England is sponsoring this PhD research to propose solution based an automated system for instant detection and notification for delays in construction projects. The research aims to develop a fully automatic system to detect project overruns and inform decision-makers to obtain timely and accurate information about detected delays, which assist them to make the right decisions at the right time to address any potential project overruns

You are cordially invited to contribute your expert knowledge and experience in *an Focus group/interview/ Survey* which will form part of the data collection for this research. Details of the study and requirements for the *Focus group/interview/ Survey* are presented in the attached information sheets.

The study aims to contribute knowledge on the subject area as well as provide recommendations towards overall improvement in the construction industry.

Appreciate your contribution to this research.

Thank you.

Yours sincerely

....

Hany Omar (Doctoral Researcher)

Participant Information Sheet

Research "*Towards an automated photogrammetry based-approach for monitoring and controlling construction site activities*"

You are invited to take part in research taking place at the University of the West of England, Bristol. It is funded by the researcher. Before you decide whether to take part, it is important for you to understand why the study is being done and what it will involve. Please read the following information carefully and if you have any queries or would like more information please contact **Hany Omar (Ph.D. student)**, Faculty of Environment and Technology, University of the West of England, Bristol hany2.omar@live.uwe.ac.uk ."

Research project title: Towards an automated photogrammetry-based approach for monitoring and controlling construction site activities.

The Ph.D. researcher is Hany Omar under the supervision of Prof. Lamine Mahdjoubi and Prof. Paul Olomolaiye

Director of studies Prof. Lamine Mahdjoubi https://people.uwe.ac.uk/Person/LamineMahdjoubi

Prof. Paul Olomolaiye https://people.uwe.ac.uk/Person/PaulOlomolaiye

Department: Department of Architecture and the Built Environment, University of the West of England, Bristol

Researcher contact information: hany2.omar@live.uwe.ac.uk

What is the aim of the research?

The research is looking at developing an original, close-range photogrammetry-based system for monitoring and controlling construction site activities. The proposed system will automatically and rapidly determine the accurate progress status in construction sites and send notifications automatically via emails and SMS to the project staff, at any given time throughout the project life. This is achieved by detecting any deviations between the as-planned and as-built schedules. Our research questions are:

1. What are the limitations of current monitoring and controlling systems in the construction industry?
2. How to collect data automatically in order to allow accurate detection of progress updates to be readily available at any time for supporting the project management decisions?

3. How to create a reliable automatic notification system via emails and SMS to inform site staff with any deviation from the as-planned schedule once occurred?

To help us answer these questions the researcher will be [conducting online focus groups via Skype, online interviews via Skype and online survey]. The aim of the online interviews will be to collect information that will be made anonymous. You will be asked to use the automated system developed as part of this study for delays detection in construction projects and providing feedback to appropriate decision-makers.

The results of our study will be analysed and used; all data will be stored in a password protected in electronic format. The results of this study will be anonymised, analysed and presented in a thesis as well as academic publications only.

Why have I been invited to take part?

As a professional with long experience in the construction industry, I'm interested in gaining information about your insights about the delays in construction and how to overcome this issue so the interview will ask you about this area. I will not be asking any questions about personal information. The purpose of the questions will be to gain information about your experience and insights for delays in construction and how to stop it using the suitable technology.

Do I have to take part?

You do not have to take part in this research. It is up to you to decide whether or not you want to be involved. If you do decide to take part, you will be given a copy of this information sheet to keep and will be asked to sign a consent form. If you do decide to take part, you are able to withdraw from the research without giving a reason until the point at which your data is anonymised and can therefore no longer be traced back to you. **This point will take place on 20th August 2020**. If you want to withdraw from the study prior to 20th August 2020, please write to Hany Omar, hany2.omar@live.uwe.ac.uk. Deciding not to take part or to withdraw from the study does not have any penalty in any form.

What will happen to me if I take part and what do I have to do?

If you agree to take part in this study, you will be asked to take part either in an online focus group discussion, an online interview via Skype, or online survey via email. Focus groups and interviews will be conducted via an online discussion via Skype, which will include seven professionals from the construction industry. The online survey will entail completing an online questionnaire survey, and a link to the questionnaire will be sent to your email address. The researcher is experienced in the subject matter and is sensitive to issues it may raise. The online focus group interview via Skype will take approximately three hours. A verbal and written explanation will be provided, prior to your involvement in the focus group. The focus group discussion will be conducted online via Skype. Online interviews will take approximately 20-30 minutes and an online survey will take 10-15 minutes. The online interviews will be conducted remotely via Skype. The researcher will call you to arrange an appointment and meet online with each interviewee individually to explain your involvement.

The subject and focus of the discussion for the focus group will be “delays in construction and how to overcome it using the technology”. However, online interviews and an online survey will focus on the effectiveness and usability of the system. Your answers will be fully anonymised.

Your interview will be recorded on a voice recorder, but the recording will not contain your name. A unique identifier code will be used to re-identify you if you choose to withdraw from the study before 20 August 2020. At the point of transcription, your voice recording will be deleted. Your data will be anonymised at this point and will be analysed with interview data from other anonymised participants.

What are the benefits of taking part?

This research is attempting to find a novel and easy way to overcome the time delays in the construction industry for which the construction industry is suffering worldwide. If you take part, you will be helping us to gain a better understanding of the reasons why delays take place and how to overcome it using technology which will leverage the construction industry worldwide.

What are the possible risks of taking part?

We do not foresee or anticipate any risk to you in taking part in this study. If, however, you feel uncomfortable at any time you can ask to stop. If you need any support during or after the interview, then the researcher will be able to put you in touch with suitable support agencies. The research team is experienced in conducting interviews and online surveys and is sensitive to the subject area. The online interviews and online surveys have been designed with these considerations in mind. Moreover, the use and observation of the developed system for the system users will be done only from your desktop or laptop which does not add any potential risk to your day-to-day activities.

What will happen to your information?

All the information we receive from you will be treated in the strictest confidence.

All the information that you give will be kept confidential and anonymised at stored in a password protected in electronic format. Any data stored externally will be on my encrypted and password protected devices; my laptop and external hard disk. Data will not be transferred or shared. No plan for hard copy research material. However, any hard copy research material will be kept in a locked and secure setting to which only the researcher will have access in accordance with the University’s and the Data Protection Act 2018 and General Data Protection Regulation requirements. Voice recordings will be destroyed securely immediately after anonymised transcription. Your anonymised data will be analysed together with other interviews and file data, and we will ensure that there is no possibility of identification or re-identification from this point.

Please check this link to recognise the rules of UWE privacy notice

https://www1.uwe.ac.uk/about/corporateinformation/datamanagement/privacynotices.aspx

Where will the results of the research study be published?

A thesis will be written containing our research findings. This thesis will be available on the University of the West of England's open-access Research Repository. A hard copy of the thesis or publications will be made available to all research participants upon request. Key findings will also be shared both within and outside the University of the West of England, the supervision team and the Ph.D. viva discussion panel. Anonymous and non-identifying direct quotes may be used for publication and presentation purposes.

Who has ethically approved this research?

The project has been reviewed and approved by the Faculty of Environment and Technology, University of the West of England University Research Ethics Committee. Any comments, questions or complaints about the ethical conduct of this study can be addressed to the Research Ethics Committee at the University of the West of England: Researchethics@uwe.ac.uk

What if something goes wrong?

Any concerns, queries and/or complaints will be handled by contacting the researcher, Hany Omar, hany2.omar@live.uwe.ac.uk in the first instance.

What if I have more questions or do not understand something?

If you would like any further information about the research please contact in the first instance:

Hany Omar, hany2.omar@live.uwe.ac.uk

Appendix 4

Focus group open-ended questions

1. After the introduction of different approaches for automatic data collection from site, what will be the most appropriate approach in your view? Is it close-range photogrammetry, Lidar or Arial photogrammetry using drones? And why?
2. How to reduce and remove the occlusion for the collected data due to the construction activities?
3. When will be the most suitable time for capturing data? And how many times should be the data captured in the day?
4. What is the most suitable media of communicating the updates, shall it be through URL sent to the decision makers, or SMS or emails? Why?
5. How frequent should the system send the automatic update, shall it be weekly, fortnightly or daily? Why?
6. When the update should be sent to the decision-maker, should it be overnight i.e. 1:00AM or early in the morning 7:00 AM once the site starts?

Appendix 5:

Interactive Excel sheet for the design of cameras

Input	
17.3	Sensor width of camera (m
13	Sensor height of camera (r
45	Focal Length of camera (m
27	Distance from Area of Inte
5280	Image width (pixels)
3956	Image height (pixels)
75	Desired Overlap (%)

Output	
GSD Width (cm/pixel)	0.196590909
GSD Height (cm/pixel)	0.197168857
Image footprint width (m)	10.38
Image footprint height (m)	7.8
Horizontal Camera Interval (m)	2.595
Vertical Camera Interval (m)	1.95

```
        if (result)
            return 0;
        return -1;
    }
    int Camera::CaptureImage(char* filename)
    {
        //0 for BMP
        //1 for JPG
        NET_DVR_SetCapturePictureMode(1);
        BOOL result = NET_DVR_CapturePicture(_realPlayHandler, filename);
        if (result)
            return 0;
        return -1;
    }

    int Camera::StartRecord(char* filename) {
        BOOL result = NET_DVR_SaveRealData(_realPlayHandler, filename);
        if (result)
            return 0;
        return -1;
    }
    int Camera::StopRecord() {
        BOOL result = NET_DVR_StopSaveRealData(_realPlayHandler);
        if (result)
            return 0;
        return -1;
    }

    // startcommand :Stop or start PTZ: 0-start, 1-stop
    int Camera::PTZControl(DWORD ptzCommand, DWORD startCommand) {

        BOOL result = NET_DVR_PTZControl(_realPlayHandler, ptzCommand,
          startCommand);
        if (result)
            return 0;
        return -1;

    }

    // startcommand :Stop or start PTZ: 0-start, 1-stop
    int Camera::PTZControl(DWORD ptzCommand, DWORD startCommand, DWORD speed) {

        BOOL result = NET_DVR_PTZControlWithSpeed(_realPlayHandler, ptzCommand,
          startCommand, speed);
        if (result)
            return 0;
        return -1;

    }
```

```cpp

int Camera::SetDetectConfig()
{
    const  char* in = "<?xml version=""1.0"" encoding=""utf - 8""?><!--req, pInBuff parameter description when getting stream capability--><StreamAbility version = ""2.0""><!--opt, specify node to return, the specified node can be the lower - level node of root node--></StreamAbility>";
    NET_DVR_GetDeviceAbility(_lUserID, STREAM_ABILITY, (char*)in, 0, (char*)&m_struAblity, 256);
    /*int m_dwDispNum = 0;

    for (int i = 0; i < m_struAblity.struBncInfo.byChanNums; i++)
    {
        m_lDispChan[m_dwDispNum] = m_struAblity.struBncInfo.byStartChan + i;
        m_dwDispNum++;
    }

    for (int i = 0; i < m_struAblity.struVgaInfo.byChanNums; i++)
    {
        m_lDispChan[m_dwDispNum] = m_struAblity.struVgaInfo.byStartChan + i;
        m_dwDispNum++;
    }

    for (int i = 0; i < m_struAblity.struHdmiInfo.byChanNums; i++)
    {
        m_lDispChan[m_dwDispNum] = m_struAblity.struHdmiInfo.byStartChan + i;
        m_dwDispNum++;
    }

    for (int i = 0; i < m_struAblity.struDviInfo.byChanNums; i++)
    {
        m_lDispChan[m_dwDispNum] = m_struAblity.struDviInfo.byStartChan + i;
        m_dwDispNum++;
    }*/

    m_DetectParamSet[0].dwSize = sizeof(NET_VCA_FIELDDETECION);
    m_DetectParamSet[0].byEnable = 1;
    m_DetectParamSet[0].byEnableDualVca = 1;
    m_DetectParamSet[0].byEnableHumanMisinfoFilter = 1;
    m_DetectParamSet[0].byEnableVehicleMisinfoFilter = 1;
    m_DetectParamSet[0].struIntrusion[0].wDuration = 300;
    m_DetectParamSet[0].struIntrusion[0].bySensitivity = 50;
    m_DetectParamSet[0].struIntrusion[0].byRate = 50;
    m_DetectParamSet[0].struIntrusion[0].byDetectionTarget = 0;
```

```
            m_DetectParamSet[0].struIntrusion[0].byPriority = 1;
            m_DetectParamSet[0].struIntrusion[0].struRegion.dwPointNum = 4;
            m_DetectParamSet[0].struIntrusion[0].struRegion.struPos[0].fX = 0.2;
            m_DetectParamSet[0].struIntrusion[0].struRegion.struPos[0].fY = 0.2;
            m_DetectParamSet[0].struIntrusion[0].struRegion.struPos[1].fX = 0.7;
            m_DetectParamSet[0].struIntrusion[0].struRegion.struPos[1].fY = 0.2;
            m_DetectParamSet[0].struIntrusion[0].struRegion.struPos[2].fX = 0.7;
            m_DetectParamSet[0].struIntrusion[0].struRegion.struPos[2].fY = 0.7;
            m_DetectParamSet[0].struIntrusion[0].struRegion.struPos[3].fX = 0.2;
            m_DetectParamSet[0].struIntrusion[0].struRegion.struPos[3].fY = 0.7;

            BOOL result = NET_DVR_SetDeviceConfig(_lUserID,
              NET_DVR_SET_FIELD_DETECTION, m_dwCount, m_lDispChan, m_dwCount *
              sizeof(NET_DVR_CHANNEL_GROUP), m_dwStatus, m_DetectParamSet,
              m_dwCount * sizeof(NET_VCA_FIELDDETECION));

            if (result)
                return 0;
            return -1;
        }


    }
```

Appendix 7: Face-to-face interviews

1. What is your background, specialty, total years of experience and experience in Dubai?
2. What is your evaluation for the system in terms of detecting and reporting the delays?
3. How did the system assist the decision makers to stop the delays?
4. What is your evaluation for the system in terms of time saving, accuracy, reliability, easy to use, cost benefit and usefulness?
5. What are the missed functions, and features in your opinion that are required to improve the efficiency and performance of the system?
6. What is the most useful function/feature you found in the system?
7. What is the least function/feature you wish to improve in the system?

Appendix 8: Method statement and risk assessment for camera installation

Purpose: Cameras, WIFI extender and server rack installation Works for WHEIDARD Substation construction monitoring.

Place of work/Substation: 132/33kV HAMR substation

Details:

1. Ensure that the valid permit is available at site before entering live station.
2. Safety measures will follow strictly to carry out the service as per M/s DEWA standard.
3. To carry out installation of Cameras, Server rack and necessary cables.

<u>Installation of Cameras:</u>

Step 1: Total 12 number of cameras will be installed inside existing HAMR S/S and New WHEIDARD S/S, location are as shown in sketch No.A101 & A102.

Step 2: CAM-01 and WIFI extender will be installed on the existing wall of **132kV GIS building** by using wall mounted bracket and drill machine as per site condition.

Step 3: CAM-02 , CAM-03 and WIFI extenders will be installed on the existing H channel of **Reactor room** mesh by using wall mounted bracket as per site condition.

Step 4: CAM-04 and WIFI extender will be installed on the existing H channel of **33/6.6kV trafo. room** by using wall mounted bracket as per site condition.

Step 5: CAM-05, CAM-06 , CAM-07 and WIFI extenders will be installed on the existing wall of **33kV SWGR room** by using mounted bracket and drill machine.

Installation of Server rack

Step 8: Sever rack will be installed inside existing **132kV building Relay room** as shown in Document No.: A103 as per site condition.

Power to Cameras and Server Rack

Step 9: Power to the server rack will be connected from existing wall mounted sockets inside relay room as per site condition and shown in Document No.A103.

Step 10: Power to CAM-01, CAM-02, CAM-03 and CAM-12 will be from 132kV main building existing sockets. Isolation will be arranged with MCB and ELCB. Necessary routing arrangement will be finalised during work.

Step 11: Power to CAM-04, CAM-05, CAM-06, CAM-07, CAM-08, CAM-09, CAM-10 and CAM-11 will be from **33kV SWGR room existing sockets**. Isolation will be arranged with MCB and ELCB. Necessary routing arrangement will be finalised during work.

System Setup: M/s BTL will carry out necessary hardware and software integration works after cameras and rack installation. This will be done inside 132kV building relay room.

Tools & Tackles:

- Drilling machine
- Man lift
- Adjustable Wrench
- Screwdriver

Safety and security: Contractor liability as per UAE Labour law and Safety rules. See attached risk assessment

Execution Table: Expected starting date as per mutual agreement.

Outage request: **No Outage required**

Starting date: 15-11-2018 working Hours: 07:30 to 17:00 Hrs

DAY WISE PROGRAM

Cameras installation for new 132/11kV WHEIDARD S/S

No	Description	November -December 2018																																	
		Sat	11	12	13	14	15	Fri	Sat	18	19	20	21	22	Fri	Sat	25	26	27	28	29	Fri	Sat	2	3	4	5	6	Fri	Sat	9	10	11	12	13
1	Cameras Installation						X			X	X	X	X	X			X																		
2	Power cables to Camers and Rack												X	X			X	X	X																
3	Server Rack Installation																			X	X														
4	System setup																			X	X			X	X	X	X	X							

To Carry out an activity safely final Risk Rating should be reduced to 20 or below. Exemption: Work covered by Permit to Work (PTW).

Hazard(s)	Hazard Effect	Person(s) at risk	Legal requirement to be complied (Yes/No)	Existing Control Measures with mechanism from hierarchy of Control for each identified hazard	Risk Rating				Additional Control Measure(s) required with mechanism from hierarchy of control for each identified hazard	Final Risk Rating			
					Number	Severity	Likelihood	Risk		Number	Severity	Likelihood	Final Risk
1. Electrocution 2. Damage to the existing property 3. Fall from Height 4. Flying objects/sharp edges /poor visibility/Access obstructions 5...Slip/Trip/Fall due to uneven path /Access	Personnel injury Fall from height Fatality Property damage Collision	Technicians Supervisors Engineers	DM COC CP chapter 16 4-2-6 4-2-7 4-2-8	1. First of all obtain a Permit form DEWA Concerned Department. 2.Strict supervision by MELCO COMPETENT PERSON 3. Strict briefing to be provided to the work force regarding ACCESS and working procedures. 4.Area shall be barricaded with appropriate signage (Working with MEWP) 5. 3rd party certificate for the MEWP 6. Obey manufacturer's written instructions before using the equipment. 7. operators 3rd party competency shall be verified before starting the work 8.Provide adequate PPE (Appropriate PPE is a mandatory requirement for that area . 9.Tool box talk must be conducted before the job starts 10.Personnel awareness, competence training 11. Access to be clear	2	5	5	50	1.Electrical connection from the live substation to run portable power tools , take prior permission/ obtain instruction from DEWA supervising staff before the work starts 2. use safe and standard tools (a) Use the right tool for the job (b) Operate tools according to the manufacturer's instructions © Keep the tools in good condition with regular maintenance	2	5	1	10

				12.Run ways leading to emergency exits shall not be obstructed or used for any other purpose. 13. ensure that trailing cables on working area are routed properly to avoid trips and falls **14.** hand tools must be secured /tied or tool belt must be used in order to avoid fall/slip. 15 Working above 1.8 meters must wear full body safety harness.					d) Provide and use properly the right personal protective equipment 3. Working method : Do not deviate from the points mentioned in the permit / documents obtained from the concerned department (DEWA). 4.First aid & Emergency preparedness. Strict supervision by the supervising staffs				
6..Adverse weather	Personnel injury/property damage	Operatives .workers	DM COC SP chapter 21 and 22	.Stop the work immediately in adverse weather condition and do not work until the inclement weather condition cleared	2	5	5	50	Strict supervision by the supervising staffs	2	5	1	10

Risk rating score

Risk is essentially a combination of three factors :

- The number of people that could be affected
- The severity of likely that persons could suffer
- The likelihood of harm actually occurring

The overall Risk can be determined using the following formula

Risk Rating = Numbers x Severity x Likelihood

The activities should be Risk Assessed as follows according to the criteria set out in Table below

Number of people affected		**Severity of injury**		**Likelihood of occurrence**	
1-5 Persons	1	Negligible	1	Improbable	0.5
6-50Persons	2	Minor	2	Remote	1
50+persons	3	Major	5	Possible	5
Public/Vulnerable persons affected (Ref.Annexure 1 a)	3	Fatal	10	Likely	10

Notes .

- If the public or vulnerable persons could be affected by the work activities the appropriate weighting should be applied
- **Negligible injuries** include bumps, small cuts and abrasions etc
- **Minor injuries** includes those injuries that could result in time off work, etc
- **Major injuries** include broken limbs, injury to eyes, asphyxiation, etc.
- **Improbable** : probability close to zero
- **Remote** : Unlikely
- **Possible**: Could occur sometime
- **Likely**: Not surprised that it will happen
- **Certain** : Most likely to happen

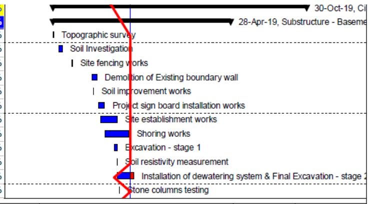
RISK RATING SCORE	**ACTION TO BE TAKEN**
UP TO 20	Risk is low : Acceptable : Additional control measures may be considered to reduce the risk, although low priority. Time ,effort and cost should be proportional to the Risk
21-50	**Risk is medium** : Unacceptable : Additional **control measures required soon** to control. **Interim measures may** be necessary **in the short term**(Activity **can** operate **subject to management and /or modification**)
51-100	**Risk is High** : Unacceptable. Additional control measures required urgently to control Risk. Interim measures required in the short term. Significant effort, time, etc. may have to control the risk. Activity should be modified to include immediate planning and action and be subject to detailed HSE assessment.
100 +	Risk totally unacceptable (Activity should not proceed in current form)

Remember Hierarchy of Control:

Elimination	Substitute	Engineering control	Administrative	Signage /warning	Training	Supervision	P

Appendix 9: Sample of the as-planned construction schedule

Civil Construction		525	19-Feb-18	23-Oct-19	19-Feb-18 A	30-Oct-19	1.92%
Substructure - Basements		367	19-Feb-18	22-Apr-19	19-Feb-18 A	28-Apr-19	36.92%
WHRD-CONST-110	Topographic survey	2	19-Feb-18	20-Feb-18	19-Feb-18 A	20-Feb-18 A	100%
WHRD-CONST-130	Soil Investigation	7	06-Mar-18	13-Mar-18	06-Mar-18 A	12-Mar-18 A	100%
WHRD-CONST-150	Site fencing works	5	17-Apr-18	22-Apr-18	05-Apr-18 A	06-Apr-18 A	100%
WHRD-CONST-125	Demolition of Existing boundary wall	7	08-Apr-18	15-Apr-18	24-May-18 A	04-Jun-18 A	0%
WHRD-CONST-4500	Soil improvement works	35	29-May-18	08-Jul-18	29-May-18 A	29-May-18 A	100%
WHRD-CONST-140	Project sign board installation works	5	17-Apr-18	22-Apr-18	09-Jun-18 A	25-Jun-18 A	100%
WHRD-CONST-170	Site establishment works	30	24-Apr-18	28-May-18	14-Jun-18 A	25-Jul-18 A	100%
WHRD-CONST-4510	Shoring works	20	06-May-18	28-May-18	27-Jun-18 A	23-Aug-18 A	100%
WHRD-CONST-160	Excavation - stage 1	8	05-May-18	13-May-18	17-Jul-18 A	26-Jul-18 A	100%
WHRD-CONST-120	Soil resistivity measurement	5	19-Mar-18	24-Mar-18	26-Jul-18 A	26-Jul-18 A	100%
WHRD-CONST-4520	Installation of dewatering system & Final Excavation - stage 2	7	09-Jul-18	16-Jul-18	26-Jul-18 A	02-Sep-18	60%
WHRD-CONST-4530	Stone columns testing	12	25-Jul-18	07-Aug-18	31-Jul-18 A	31-Jul-18 A	100%



Actual Level of Effort — Critical Remaining Work
Actual Work — Milestone
Remaining Work — summary

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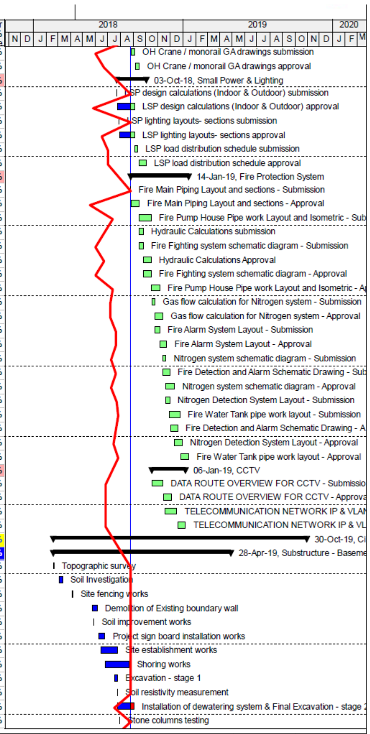
Data date - 27-Aug-18

Date	Revision	Checked	Approved
27-Aug-18	MPR-06	SV/aa	PM

Activity ID	Activity Name	BL Project Duration	BL Project Start	BL Project Finish	Start	Finish	Nonlabor Units % Complete
WHRD-ENG-680	OH Crane / monorail GA drawings submission	21	10-Apr-18	08-May-18	28-Aug-18	05-Sep-18	0%
WHRD-ENG-1020	OH Crane / monorail GA drawings approval	14	29-May-18	17-Jun-18	06-Sep-18	16-Sep-18	0%
Small Power & Lighting		91	12-Mar-18	16-Jul-18	24-Jul-18 A	03-Oct-18	50%
WHRD-ENG-220	LSP design calculations (Indoor & Outdoor) submission	21	12-Mar-18	09-Apr-18	24-Jul-18 A	24-Jul-18 A	100%
WHRD-ENG-370	LSP design calculations (Indoor & Outdoor) approval	14	10-Apr-18	29-Apr-18	25-Jul-18 A	04-Sep-18	50%
WHRD-ENG-410	LSP lighting layouts- sections submission	21	10-Apr-18	08-May-18	29-Jul-18 A	29-Jul-18 A	100%
WHRD-ENG-660	LSP lighting layouts- sections approval	14	09-May-18	28-May-18	30-Jul-18 A	04-Sep-18	50%
WHRD-ENG-1240	LSP load distribution schedule submission	21	29-May-18	26-Jun-18	05-Sep-18	13-Sep-18	0%
WHRD-ENG-1600	LSP load distribution schedule approval	14	27-Jun-18	16-Jul-18	16-Sep-18	03-Oct-18	0%
Fire Protection System		189	12-Mar-18	29-Nov-18	26-Aug-18 A	14-Jan-19	5%
WHRD-ENG-230	Fire Main Piping Layout and sections - Submission	21	12-Mar-18	09-Apr-18	26-Aug-18 A	26-Aug-18 A	100%
WHRD-ENG-420	Fire Main Piping Layout and sections - Approval	14	10-Apr-18	29-Apr-18	28-Aug-18	16-Sep-18	0%
WHRD-ENG-2320	Fire Pump House Pipe work Layout and Isometric - Submission	21	15-Jul-18	12-Aug-18	16-Sep-18	15-Oct-18	0%
WHRD-ENG-950	Hydraulic Calculations submission	21	29-May-18	26-Jun-18	17-Sep-18	25-Sep-18	0%
WHRD-ENG-620	Fire Fighting system schematic diagram - Submission	21	30-Apr-18	28-May-18	17-Sep-18	25-Sep-18	0%
WHRD-ENG-1290	Hydraulic Calculations Approval	14	27-Jun-18	16-Jul-18	26-Sep-18	15-Oct-18	0%
WHRD-ENG-960	Fire Fighting system schematic diagram - Approval	14	29-May-18	17-Jun-18	26-Sep-18	15-Oct-18	0%
WHRD-ENG-2700	Fire Pump House Pipe work Layout and Isometric - Approval	14	13-Aug-18	30-Aug-18	15-Oct-18	04-Nov-18	0%
WHRD-ENG-1580	Gas flow calculation for Nitrogen system - Submission	21	17-Jul-18	14-Aug-18	16-Oct-18	24-Oct-18	0%
WHRD-ENG-1920	Gas flow calculation for Nitrogen system - Approval	14	15-Aug-18	03-Sep-18	25-Oct-18	13-Nov-18	0%
WHRD-ENG-1590	Fire Alarm System Layout - Submission	21	15-Aug-18	12-Sep-18	25-Oct-18	04-Nov-18	0%
WHRD-ENG-1940	Fire Alarm System Layout - Approval	14	13-Sep-18	02-Oct-18	05-Nov-18	22-Nov-18	0%
WHRD-ENG-1930	Nitrogen system schematic diagram - Submission	21	15-Aug-18	12-Sep-18	12-Nov-18	20-Nov-18	0%
WHRD-ENG-2200	Fire Detection and Alarm Schematic Drawing - Submission	21	11-Sep-18	09-Oct-18	12-Nov-18	29-Nov-18	0%
WHRD-ENG-2290	Nitrogen system schematic diagram - Approval	14	13-Sep-18	02-Oct-18	21-Nov-18	10-Dec-18	0%
WHRD-ENG-2310	Nitrogen Detection System Layout - Submission	21	13-Sep-18	11-Oct-18	21-Nov-18	29-Nov-18	0%
WHRD-ENG-3440	Fire Water Tank pipe work layout - Submission	21	14-Oct-18	11-Nov-18	27-Nov-18	25-Dec-18	0%
WHRD-ENG-2540	Fire Detection and Alarm Schematic Drawing - Approval	14	10-Oct-18	29-Oct-18	02-Dec-18	19-Dec-18	0%
WHRD-ENG-2690	Nitrogen Detection System Layout - Approval	14	14-Oct-18	31-Oct-18	11-Dec-18	30-Dec-18	0%
WHRD-ENG-3540	Fire Water Tank pipe work layout - Approval	14	12-Nov-18	29-Nov-18	26-Dec-18	14-Jan-19	0%
CCTV		59	22-Jul-18	10-Oct-18	16-Oct-18	06-Jan-19	0%
WHRD-ENG-2970	DATA ROUTE OVERVIEW FOR CCTV - Submission	21	22-Jul-18	19-Aug-18	16-Oct-18	13-Nov-18	0%
WHRD-ENG-3170	DATA ROUTE OVERVIEW FOR CCTV - Approval	14	20-Aug-18	06-Sep-18	14-Nov-18	03-Dec-18	0%
WHRD-ENG-3260	TELECOMMUNICATION NETWORK IP & VLAN PLAN for CCTV - Submission	21	23-Aug-18	20-Sep-18	19-Nov-18	17-Dec-18	0%
WHRD-ENG-3470	TELECOMMUNICATION NETWORK IP & VLAN PLAN for CCTV - Approval	14	23-Sep-18	10-Oct-18	18-Dec-18	06-Jan-19	0%
Civil Construction		525	19-Feb-18	23-Oct-19	19-Feb-18 A	30-Oct-19	1.92%
Substructure - Basements		367	19-Feb-18	22-Apr-19	19-Feb-18 A	28-Apr-19	36.92%
WHRD-CONST-110	Topographic survey	2	19-Feb-18	20-Feb-18	19-Feb-18 A	20-Feb-18 A	100%
WHRD-CONST-130	Soil Investigation	7	06-Mar-18	13-Mar-18	06-Mar-18 A	12-Mar-18 A	100%
WHRD-CONST-150	Site fencing works	5	17-Apr-18	22-Apr-18	05-Apr-18 A	06-Apr-18 A	100%
WHRD-CONST-125	Demolition of Existing boundary wall	7	08-Apr-18	15-Apr-18	24-May-18 A	04-Jun-18 A	0%
WHRD-CONST-4500	Soil improvement works	35	29-May-18	08-Jul-18	29-May-18 A	29-May-18 A	100%
WHRD-CONST-140	Project sign board installation works	5	17-Apr-18	22-Apr-18	09-Jun-18 A	25-Jun-18 A	100%
WHRD-CONST-170	Site establishment works	30	24-Apr-18	28-May-18	14-Jun-18 A	25-Jul-18 A	100%
WHRD-CONST-4510	Shoring works	20	06-May-18	28-May-18	27-Jun-18 A	23-Aug-18 A	100%
WHRD-CONST-160	Excavation - stage 1	8	05-May-18	13-May-18	17-Jul-18 A	26-Jul-18 A	100%
WHRD-CONST-120	Soil resistivity measurement	5	19-Mar-18	24-Mar-18	26-Jul-18 A	26-Jul-18 A	100%
WHRD-CONST-4520	Installation of dewatering system & Final Excavation - stage 2	7	09-Jul-18	16-Jul-18	26-Jul-18 A	02-Sep-18	60%
WHRD-CONST-4530	Stone columns testing	12	25-Jul-18	07-Aug-18	31-Jul-18 A	31-Jul-18 A	100%



Actual Level of Effort — Critical Remaining Work
Actual Work — Milestone
Remaining Work — summary

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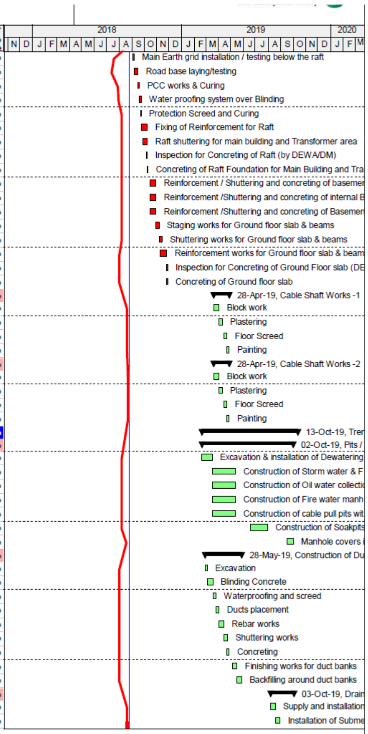
Data date - 27-Aug-18

Date	Revision	Checked	Approved
27-Aug-18	MPR-06	SV/aa	PM

Activity ID	Activity Name	BL Project Duration	BL Project Start	BL Project Finish	Start	Finish	Nonlabor Units % Complete
WHRD-CONST-180	Main Earth grid installation / testing below the raft	5	17-Jul-18	22-Jul-18	03-Sep-18	06-Sep-18	0%
WHRD-CONST-190	Road base laying/testing	7	17-Jul-18	24-Jul-18	06-Sep-18	16-Sep-18	0%
WHRD-CONST-200	PCC works & Curing	7	08-Aug-18	15-Aug-18	16-Sep-18	19-Sep-18	0%
WHRD-CONST-210	Water proofing system over Blinding	6	16-Aug-18	22-Aug-18	19-Sep-18	23-Sep-18	0%
WHRD-CONST-220	Protection Screed and Curing	6	23-Aug-18	29-Aug-18	22-Sep-18	23-Sep-18	0%
WHRD-CONST-230	Fixing of Reinforcement for Raft	14	30-Aug-18	15-Sep-18	23-Sep-18	09-Oct-18	0%
WHRD-CONST-240	Raft shuttering for main building and Transformer area	10	04-Sep-18	15-Sep-18	27-Sep-18	09-Oct-18	0%
WHRD-CONST-250	Inspection for Concreting of Raft (by DEWA/DM)	1	16-Sep-18	16-Sep-18	08-Oct-18	09-Oct-18	0%
WHRD-CONST-260	Concreting of Raft Foundation for Main Building and Transformer area	1	16-Sep-18	16-Sep-18	09-Oct-18	10-Oct-18	0%
WHRD-CONST-280	Reinforcement / Shuttering and concreting of basement walls	14	20-Sep-18	06-Oct-18	14-Oct-18	30-Oct-18	0%
WHRD-CONST-290	Reinforcement /Shuttering and concreting of internal Basement Columns	14	20-Sep-18	06-Oct-18	14-Oct-18	30-Oct-18	0%
WHRD-CONST-300	Reinforcement /Shuttering and concreting of Basement wall in Transformer are:	14	20-Sep-18	06-Oct-18	14-Oct-18	30-Oct-18	0%
WHRD-CONST-340	Staging works for Ground floor slab & beams	6	07-Oct-18	13-Oct-18	30-Oct-18	06-Nov-18	0%
WHRD-CONST-370	Shuttering works for Ground floor slab & beams	8	14-Oct-18	22-Oct-18	06-Nov-18	15-Nov-18	0%
WHRD-CONST-390	Reinforcement works for Ground floor slab & beams	10	16-Oct-18	27-Oct-18	08-Nov-18	26-Nov-18	0%
WHRD-CONST-440	Inspection for Concreting of Ground Floor slab (DEWA/DM)	1	28-Oct-18	28-Oct-18	26-Nov-18	27-Nov-18	0%
WHRD-CONST-450	Concreting of Ground floor slab	1	28-Oct-18	28-Oct-18	26-Nov-18	27-Nov-18	0%
Cable Shaft Works -1		32	16-Mar-19	21-Apr-19	21-Mar-19	28-Apr-19	0%
WHRD-CONST-2310	Block work	10	16-Mar-19	26-Mar-19	21-Mar-19	02-Apr-19	0%
WHRD-CONST-2560	Plastering	7	27-Mar-19	03-Apr-19	02-Apr-19	10-Apr-19	0%
WHRD-CONST-2780	Floor Screed	7	08-Apr-19	15-Apr-19	14-Apr-19	22-Apr-19	0%
WHRD-CONST-2920	Painting	5	16-Apr-19	21-Apr-19	22-Apr-19	28-Apr-19	0%
Cable Shaft Works -2		32	17-Mar-19	22-Apr-19	21-Mar-19	28-Apr-19	0%
WHRD-CONST-2340	Block work	10	17-Mar-19	27-Mar-19	21-Mar-19	02-Apr-19	0%
WHRD-CONST-2600	Plastering	7	28-Mar-19	04-Apr-19	02-Apr-19	10-Apr-19	0%
WHRD-CONST-2800	Floor Screed	7	09-Apr-19	16-Apr-19	14-Apr-19	22-Apr-19	0%
WHRD-CONST-2930	Painting	5	17-Apr-19	22-Apr-19	22-Apr-19	28-Apr-19	0%
Trenches, Ducts and Drainage		208	28-Jan-19	26-Sep-19	20-Feb-19	13-Oct-19	0%
Pits / Soakway		205	28-Jan-19	23-Sep-19	20-Feb-19	02-Oct-19	0%
WHRD-CONST-1110	Excavation & installation of Dewatering system	20	28-Jan-19	19-Feb-19	20-Feb-19	16-Mar-19	0%
WHRD-CONST-1460	Construction of Storm water & Foul drainage manholes	50	20-Feb-19	18-Apr-19	16-Mar-19	13-May-19	0%
WHRD-CONST-1490	Construction of Oil water collection pits	50	20-Feb-19	18-Apr-19	16-Mar-19	13-May-19	0%
WHRD-CONST-1500	Construction of Fire water manholes	50	20-Feb-19	18-Apr-19	16-Mar-19	13-May-19	0%
WHRD-CONST-1510	Construction of cable pull pits with ducts encasement	50	20-Feb-19	18-Apr-19	16-Mar-19	13-May-19	0%
WHRD-CONST-2510	Construction of Soakpits & neutralization pit	35	27-May-19	06-Jul-19	19-Jun-19	30-Jul-19	0%
WHRD-CONST-4040	Manhole covers installation	14	08-Sep-19	23-Sep-19	16-Sep-19	02-Oct-19	0%
Construction of Duct bank		76	30-Jan-19	28-Apr-19	28-Feb-19	28-May-19	0%
WHRD-CONST-1730	Excavation	5	30-Jan-19	04-Feb-19	28-Feb-19	06-Mar-19	0%
WHRD-CONST-1780	Blinding Concrete	10	05-Feb-19	16-Feb-19	06-Mar-19	18-Mar-19	0%
WHRD-CONST-1880	Waterproofing and screed	7	17-Feb-19	24-Feb-19	18-Mar-19	26-Mar-19	0%
WHRD-CONST-2050	Ducts placement	7	25-Feb-19	04-Mar-19	26-Mar-19	03-Apr-19	0%
WHRD-CONST-2200	Rebar works	10	05-Mar-19	16-Mar-19	03-Apr-19	15-Apr-19	0%
WHRD-CONST-2480	Shuttering works	8	17-Mar-19	25-Mar-19	15-Apr-19	24-Apr-19	0%
WHRD-CONST-2620	Concreting	5	23-Mar-19	27-Mar-19	21-Apr-19	27-Apr-19	0%
WHRD-CONST-2830	Finishing works for duct banks	10	06-Apr-19	16-Apr-19	05-May-19	16-May-19	0%
WHRD-CONST-3060	Backfilling around duct banks	10	17-Apr-19	28-Apr-19	16-May-19	28-May-19	0%
Drainage & Plumbing		50	31-Jul-19	26-Sep-19	06-Aug-19	03-Oct-19	0%
WHRD-CONST-3660	Supply and installation of Water Tanks and associated Pipe work	10	31-Jul-19	11-Aug-19	06-Aug-19	18-Aug-19	0%
WHRD-CONST-3730	Installation of Submersible Pump	10	12-Aug-19	22-Aug-19	18-Aug-19	29-Aug-19	0%



Actual Level of Effort — Critical Remaining Work
Actual Work — Milestone
Remaining Work — summary

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Data date - 27-Aug-18

Date	Revision	Checked	Approved
27-Aug-18	MPR-06	SV/aa	PM

Appendix 10: Online survey questionnaire

Participant's Background:

1. Which of the following best describes you?
   ☐Owner/Client
   ☐Contractor/subcontractor
   ☐Consultant (Design)
   ☐Consultant (supervision)
   ☐BIM specialist/Manager
   ☐Software programmer
   ☐Others *(Please Specify)*Click or tap here to enter text.
2. Please specify the overall number of years in the construction industry:
   ☐Less than 5 years
   ☐5-10 years
   ☐11-20 years
   ☐More than 20 years
3. Please state the number of years of experience in construction sector in Dubai:
   ☐Less than 2 years
   ☐2-5 years
   ☐6-10 years
   ☐More than 10
4. Have you ever suffer from delays in any of your previous or current construction projects?
   ☐ Yes ☐ No
5. How many causes you can estimate for the delays in construction projects?
   ☐Less than 2
   ☐ 2-5 years
   ☐ 6-10 years
   ☐ More than 10
6. I can propose solution to stop or mitigate delays in construction projects.
   ☐ Yes ☐ No
7. If you agree to participant in the focus group interview please furnish the following details

Mobile number: Email address:

1. **Stage 2-II development stage (case study)**

The second survey questionnaire aims to validate the proposed system by measuring the satisfaction level for the end-users of the system.

The following questionnaire will check the following six areas:

A. One question for **Participants background**
B. Five questions for **System quality**
C. Ten questions for **Information quality**
D. Six questions for **Perceived usefulness**
E. Four questions for **Overall satisfaction**
F. Two questions for **Usage of the system**
G. Six questions for **Importance of the system**

Participant's Background:

1. Which of the following best describes you?

   ☐Owner/Client

   ☐Contractor/subcontractor

   ☐Consultant (supervision)

   ☐BIM specialist/Manager

   ☐Others *(Please Specify)*Click or tap here to enter text.

2. How many years of experience do you have

3. Have you ever worked for DEWA 132/11 KV substations in the last 10 years

   ☐ Yes ☐ No

System quality

1. AMAC system is easy to use

1- Strongly agree	2-Agree	3-Neutral	4-Disagree	5-Strongly disagree
☐	☐	☐	☐	☐

2. AMAC system is user friendly

1- Strongly agree	2-Agree	3-Neutral	4-Disagree	5-Strongly disagree
☐	☐	☐	☐	☐

3. AMAC system is easy to learn

1- Strongly agree	2-Agree	3-Neutral	4-Disagree	5-Strongly disagree
☐	☐	☐	☐	☐

4. I find it easy to get AMAC system to do what I want it to do.

1- Strongly agree	2-Agree	3-Neutral	4-Disagree	5-Strongly disagree
☐	☐	☐	☐	☐

5. It is easy for me to become skillful at using AMAC system.

1- Strongly agree	2-Agree	3-Neutral	4-Disagree	5-Strongly disagree
☐	☐	☐	☐	☐

Information quality

1. AMAC system outputs are presented in a useful format

1- Strongly agree	2-Agree	3-Neutral	4-Disagree	5-Strongly disagree
☐	☐	☐	☐	☐

2. I'm satisfied with the accuracy of AMAC system

1- Strongly agree	2-Agree	3-Neutral	4-Disagree	5-Strongly disagree
☐	☐	☐	☐	☐

3. AMAC system offers clear information

1- Strongly agree	2-Agree	3-Neutral	4-Disagree	5-Strongly disagree
☐	☐	☐	☐	☐

4. AMAC system provides sufficient information

1- Strongly agree	2-Agree	3-Neutral	4-Disagree	5-Strongly disagree
☐	☐	☐	☐	☐

5. AMAC system provides accurate daily progress updates

1- Strongly agree	2-Agree	3-Neutral	4-Disagree	5-Strongly disagree
☐	☐	☐	☐	☐

6. I got the information I need on time

1- Strongly agree	2-Agree	3-Neutral	4-Disagree	5-Strongly disagree
☐	☐	☐	☐	☐

7. AMAC system provides reports respond to exactly what I need

1- Strongly agree	2-Agree	3-Neutral	4-Disagree	5-Strongly disagree
☐	☐	☐	☐	☐

8. AMAC system provides precise information that I need

1- Strongly agree	2-Agree	3-Neutral	4-Disagree	5-Strongly disagree
☐	☐	☐	☐	☐

9. AMAC system provides information contents that meets my needs

1- Strongly agree	2-Agree	3-Neutral	4-Disagree	5-Strongly disagree
☐	☐	☐	☐	☐

Perceived usefulness

1. Using AMAC system enabled me to accomplish my daily tasks more quickly

1- Strongly agree	2-Agree	3-Neutral	4-Disagree	5-Strongly disagree
☐	☐	☐	☐	☐

2. Using AMAC system enabled me to accomplish my tasks more efficiently

1- Strongly agree	2-Agree	3-Neutral	4-Disagree	5-Strongly disagree
☐	☐	☐	☐	☐

3. Using AMAC system improved my performance

1- Strongly agree	2-Agree	3-Neutral	4-Disagree	5-Strongly disagree
☐	☐	☐	☐	☐

4. Using AMAC system improved the productivity

1- Strongly agree	2-Agree	3-Neutral	4-Disagree	5-Strongly disagree
☐	☐	☐	☐	☐

5. Using AMAC system enhanced effectiveness in the project

1- Strongly agree	2-Agree	3-Neutral	4-Disagree	5-Strongly disagree
☐	☐	☐	☐	☐

6. Using AMAC system made it easier to me to do my tasks

1- Strongly agree	2-Agree	3-Neutral	4-Disagree	5-Strongly disagree
☐	☐	☐	☐	☐

Overall satisfaction

1. AMAC system assisted me to improve my performance for efficient carrying out of my roles and responsibilities

1- Strongly agree	2-Agree	3-Neutral	4-Disagree	5-Strongly disagree
☐	☐	☐	☐	☐

2. AMAC system is efficient

1- Strongly agree	2-Agree	3-Neutral	4-Disagree	5-Strongly disagree
☐	☐	☐	☐	☐

3. AMAC system is effective

1- Strongly agree	2-Agree	3-Neutral	4-Disagree	5-Strongly disagree
☐	☐	☐	☐	☐

4. Overall, I’m satisfied with the system

1- Strongly agree	2-Agree	3-Neutral	4-Disagree	5-Strongly disagree
☐	☐	☐	☐	☐

5. The system is fully automated, does not require human intervention for data collection and analysis

1- Strongly agree	2-Agree	3-Neutral	4-Disagree	5-Strongly disagree
☐	☐	☐	☐	☐

6. The results are reliable and always correct

1- Strongly agree	2-Agree	3-Neutral	4-Disagree	5-Strongly disagree
☐	☐	☐	☐	☐

Usage of the system

1. Which feature you have used the most

1- Dashboard	2-4D viewer	3-Cameras
☐	☐	☐

2. Which feature you have used the least

1- Dashboard	2-4D viewer	3-Cameras
☐	☐	☐

3. If AMAC system is not mandatory, I would still use it

☐ Yes ☐ No

4. On average, I use AMAC system Choose an item. per week
5. If you have the choice to use one of the following systems which one you are going to use

☐ AMAC system ☐ the system you are always using

Importance of the system

1. According to your experience as a user for AMAC system, please rate the importance of the system.

1- Very important	2- Important	3-Moderately Important	4- Slightly Important	5-Unimportant
☐	☐	☐	☐	☐

1- Very Relevant	2- Relevant	3-Neutral	4- Irrelevant	5-Not at all Relevant
☐	☐	☐	☐	☐

1- Extremely Useful	2- Useful	3-Neutral	4- useless	5-Extremely useless
☐	☐	☐	☐	☐

If you would like to express any further opinion about this system, please add it in below section

Click or tap here to enter text.

Appendix 11: Author's publications

Published journal peppers

Elhendawi, A., **Omar, H.**, Elbeltagi, E and Smith, A. (2020). Practical approach for paving the way to motivate BIM non-users for adopting BIM: A case study of KSA AEC industry, *International journal of BIM and Engineering science,* vol 2(2), pp. 01-22.

Omar, H., Mahdjoubi, L and Kheder,G. (2018). Towards an automated photogrammetry-based approach for monitoring and controlling construction site activities, *Computers in industry journal,* vol 98, pp.172–182.

Conference papers

Omar, H and Dulaimi, M. (2015) Using BIM to automate the construction site activities (Published conference paper, presented in BIM 2015 conference, Bristol, UK),

Omar, H and Dulaimi, M. (2014) Creating a sustainable future: Solutions for the construction waste (Conference paper, Published& presented in 14 December 2014, in the first CIB-MENA conference).

Under Publication

Omar, H., Dulaimi, M. and Mahdjoubi, L. Challenges to the Effective Diffusion for BIM late adopters: Case study of UAE AEC industry (*Under publication, Engineering, Construction, Architecture and Management Journal*).

Omar, H., and Mahdjoubi, L. Analytical study of the root causes for overruns in public construction projects (under publication, *Journal of Construction Engineering and Management*).