

A Decision Support Framework for Site Safety Monitoring using RFID and BIM

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A Decision Support Framework for Site Safety Monitoring using RFID and BIM

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DECLARATION

This thesis is presented as an original contribution to earn a Doctorate of Philosophy degree at the University of Salford, Salford, United Kingdom. The work here has not been previously submitted to meet requirements for an award at any higher education institution under my name or that of any other individuals. To the best of my knowledge and belief, the thesis contains no materials previously published or written by another person except where due reference is made and acknowledged.

A handwritten signature in black ink, appearing to read 'Anoop Sattineni', with a stylized, cursive script.

Anoop Sattineni

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ABBREVIATIONS

2D	Two Dimensional
3D	Three Dimensional
AEC	Architecture, Engineering and Construction
AIA	American Institute of Architecture
API	Application Programming Interface
AR	Augmented Reality
BIM	Building Information Model
CDM	Construction Design and Management
DSS	Decision Support System
ENR	Engineering News Record
GC	General Contractor
HSE	Health and Safety Executive
HVAC	Heating Venting and Air-Conditioning
IAI	International Alliance for Interoperability
IPD	Integrated Project Delivery
IR	Infrared
JSA	Job Safety Analysis
NBIMS	National Building Information Model Standard
OSHA	Occupational Safety And Health Administration
RFID	Radio Frequency Identification
RSSI	Received Signal Strength Indication
RTLS	Real Time Location Systems
TSA	Task Safety Analysis
VR	Virtual Reality
WLAN	Wireless Local Area Network

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Abstract

Supervision of construction workers on a site is crucial to ensure construction worker safety, to maintain the quality of work performed and to maintain acceptable levels of productivity. The act of supervision itself requires the site superintendent to physically monitor workers in an environment that is constantly changing throughout the various phases of construction. This can be a complicated task on a medium to large building site with several trades working simultaneously on multiple floors or areas. There exists a need for construction superintendents to know the location of construction workers within a site. Academicians and industry professionals have demonstrated the use of Radio Frequency Identification (RFID) Tags in construction applications in the past few years. RFID tags have successfully been used to track construction materials, equipment and tools. Studies indicate that the use of RFID tags in construction improves the overall process of construction. Building information modeling (BIM) technology is emerging as the industry standard in the architecture, engineering and construction (AEC) sector. BIM is being used as a comprehensive design, management, visualization, communication and facility maintenance and management tool. This research presents the creation of a decision support framework for site supervision based on monitoring construction workers by combining RFID technology with BIM. A conceptual decision support framework to monitor site safety was developed by interviewing site superintendents. Conducting a web-based questionnaire of construction industry professionals validated the framework. A proof-of-concept virtual prototype was created to track the movement of construction workers using RFID and BIM. The procedures undertaken to create the conceptual framework and the virtual prototype are described in the thesis.

CHAPTER 1

INTRODUCTION

1.1 Research Overview

The construction industry has one of the highest workplace accident rates amongst all industries (Cigularov et al., 2010). The nature of the industry inherently pre-disposes it to accident occurrence, as the physical attributes of the site are constantly changing with employees from various trades working simultaneously on construction tasks (Hinze et al., 1998). Many construction tasks take place simultaneously, and in some cases within a congested site and often have varying levels of safety risks associated with them (Bansal, 2011). Construction workers often have to be in an awkward physical stance for extended time periods to install materials, causing fatigue to the workers and may potentially lead to accidents (Gillen et al., 2002). It has been shown that a majority of construction accidents occur due to unsafe acts by workers, more so than unsafe conditions on the construction site (Sousa et al., 2014). Research has shown that accidents are most likely to occur when workers are moving around within the construction site to access materials or work areas (HSE, 2003). In addition to these issues, there is significant turnover of workers in the construction industry making it harder to train workers in safety practices (Hinze, 1978). A number of factors to determine and address the causes of accidents in the construction industry have been proposed over the past two decades; however accident data does not indicate any substantial decline within the construction industry (Abdelhamid and Everett, 2000; Bureau of Labor Statistics, n.d.).

Safety on a construction project is driven by several issues such as site layout, site location, construction schedule, safety training provided to workers, safety monitoring on the site, worker morale, culture within the company, safety considerations during the design phase, attitudes towards safety, etc. However, supervision of construction workers has been identified as a key aspect in maintaining safety within the construction site (Aksorn and Hadikusumo, 2008). The lack of proper supervision has been attributed as one of the causes for adverse safety performance on construction projects (Tam et al., 2004). Mandatory safety training and credentials are part of the construction industry practices in making sure that supervisors are prepared to handle site safety related issues. However studies have also shown that these credentials alone are not enough to prepare safety supervisors to effectively manage the construction site (Hardison et al., 2014). This research has found that apart from maintaining a safe work

environment, the supervisor is responsible for production, material management, schedule, coordination, managing subcontractors on site and other issues. It is not possible for the supervisor to keep an eye on workers at all times during a typical day on the construction site. This research found that knowing the location of construction workers within the site is critical for the superintendent to make informed decisions related to safety on a construction site.

Advancements in computing technologies in society and their adoption within the construction industry have resulted in several improvements in maintaining a safe construction site (Li et al., 2012; Li and Liu, 2012). The use of multiple technological systems for safety management and monitoring have been proposed (Aguilar and Hewage, 2013). Use of ‘Virtual Reality’ (VR) solutions has been promoted to visualise the entire site activities in real time to enhance safety monitoring (Cheng and Teizer, 2013). The use of advanced tracking technologies are proposed for ensuring that workers are wearing their ‘Personal Protective Equipment’ (PPE) while they are on the site (Barro-Torres et al., 2012). The use of sensing technologies is proposed in various construction applications for safety monitoring (Choe et al., 2014).

Building Information Modelling (BIM) represents a seismic shift in the nature of how the Architecture, Engineering and Construction industries (AEC) work and interact with one another (McGraw Hill Construction, 2012). In the last few years BIM has been increasingly adopted in the construction industry and is currently being used in a number of ways, including to improve the design, construction and facility maintenance processes in the built environment (Eastman et al., 2011; Nader et al., 2013; Barlish and Sullivan, 2012; Azhar et al., 2008). The use of BIM as a visualisation tool in and of itself has been shown to have great benefits to the AEC industries (Yan et al., 2011; Gu and London, 2010).

Meanwhile, tracking technologies such as Radio Frequency Identification (RFID) have been identified as being capable of improving the construction process (Kumar, 2007). The use of RFID technology in the construction industry has been validated by several researchers who demonstrated that materials, tools and equipment can be tracked

electronically in real time (Demiralp et al., 2012; Grau et al., 2012; Song and Eldin, 2012). The use of RFID was also proposed to alert workers when they enter a dangerous zone within the construction site by tracking the location of workers (Park and Kim, 2013).

This research aims to create a framework for safety monitoring using the location of workers on a construction site by combining RFID and BIM technologies. The site superintendent can use this combination of technologies to make decisions related to safety in real time. By enabling the site superintendent to locate personnel within the site, it also provides the site supervisor an additional measure to ensure that workers are not present in areas where they are not trained to be and that workers are in the locations where they are assigned to be working.

A conceptual framework was developed to combine RFID and BIM technologies to track construction worker movement on site. The conceptual framework was developed from the qualitative data collected by interviewing nineteen construction site superintendents in the Southern United States. The use of RFID and BIM based conceptual framework for safety monitoring was validated by one hundred and thirty responses in an Internet survey of construction industry professionals. A demonstrator software prototype was developed using ‘Tekla Structures’ and ‘Identec RFID Solutions’, to implement the proposed framework of safety monitoring by using the location of workers within a construction site. Finally, scenario simulations using volunteer actors were conducted to evaluate the demonstrator software prototype.

1.2 Research Question

The primary research question for the study is framed as: *“How can site safety decision making be enabled by monitoring the location of construction workers using RFID and BIM?”*

In the process of answering the research question, several related questions would need to be answered as well: Why do accidents occur in construction? What are the current methods of site supervision of construction personnel, with respect to safety? What are

the available technological tools to locate construction personnel in an environment that is constantly evolving? What are the key scenarios in which these technologies might be useful in site supervision, from a safety perspective? Are there applications of this technology for virtual and remote supervision, from a safety perspective?

1.3 Aim & Objectives

➤ Aim

The aim of this study is to develop a decision support framework for construction site safety monitoring by combining RFID with BIM in a virtual environment.

➤ Objectives

1. Understand existing methods for construction site safety monitoring and supervision.
2. Investigate possible uses of combining RFID and BIM technologies in the construction industry.
3. Develop a conceptual framework for site safety supervision based on location monitoring of personnel using RFID and BIM in a virtual environment.
4. Validate the proposed conceptual framework for site safety monitoring using RFID and BIM.
5. Develop and evaluate a demonstrator software prototype to monitor site safety using the RFID and BIM framework.

1.4 Scope of the Research

The scope of a thesis is an explicit discussion of what is included and what is excluded in the conduct of the research (Evans et al., 2011). In this section, issues that are central to the thesis are addressed, in terms of defining the scope for this research.

- **Safety:** A number of issues affect the safety outcomes on a construction project including training provided to workers, safety considerations during design, supervision of workers, etc. Since this research is about safety monitoring of construction workers, issues of supervision for safety, significance of location monitoring for safety and safety concerns of superintendents as they relate to worker

location, during typical construction activities are closely examined. Input from construction professionals about these issues will be used to develop and validate a decision support framework for site safety monitoring using RFID and BIM. An in-depth consideration is not given to related issues such as design considerations for safety, causes of accidents, organisational safety culture, fall prevention, safety in confined spaces and productivity pressures on safety, in the conduct of this research, since these issues are not the primary focus for this research.

- **Sensing and Visualisation Technologies:** The use of sensing technologies such as RFID systems, GPS systems, indoor GPS systems, wireless sensor networks and Zigbee systems is increasingly seen in the construction industry. Each of these technologies has unique capabilities and is considered suitable in particular applications. This research proposes the use of active RFID technology for safety monitoring. The use of RFID technology in construction applications is investigated and a case for using RFID technology for this research is made. However, detailed comparisons of various sensing technologies are not included in this study, since the primary focus is not to determine the most appropriate technology for location monitoring; moreover, detailed investigations are underway to address the many sensing technologies and their suitability in construction applications (Behzadan et al., 2008; Caron et al., 2007; Shen et al., 2008). Nevertheless, justification for using active RFID technology in this research is addressed. Several methods of determining the location of RFID tags are available. Various algorithms can approximate the location of an RFID tag; however, the precise location of an RFID tag cannot be determined but can only be approximated. A detailed investigation of the best method for determining the location of an RFID tag is not considered in this study as this issue is currently under active investigation by other researchers (Khoury and Kamat, 2009; Li and Becerik-Gerber, 2011). Issues of best technology for location monitoring on a construction site and best methods for determining the location of an RFID tag are vast enough to be considered in a separate study. Since this research has to conform to strict university guidelines regarding submission timelines, these issues were not considered; furthermore, they are not the primary focus of this research.

Several three dimensional visualisation technologies are prevalent in the construction industry including BIM, VR, Augmented Reality (AR) and holographic images. Similar to issues regarding location-monitoring technologies, each of the listed visualisation technologies can be considered in separate study and not the primary focus of this study, therefore considered beyond the scope of this research. A detailed investigation comparing various visualisation tools is not explored in this research, owing to justifications listed earlier of primary focus of this research and time constraints. However, a case for using BIM for safety monitoring in this research is made. Within BIM several software platforms are available for customising a solution to incorporate RFID technology. Since this research is about safety on a construction site, a detailed comparison of various software programs is considered outside the scope of this research.

- **Demonstrator Software Development and Testing:** Demonstrator software to implement the proposed framework is developed as part of this research. The prototype is developed with limited functionality and is not intended as a working version to implement the framework. The prototype is tested in a simulated indoor environment using volunteer actors as construction workers. Since the purpose of testing the prototype is to demonstrate the effectiveness of using the proposed framework for safety monitoring, only limited aspects of the framework proposed were tested as part of the prototype evaluation.

1.5 Rationale for this Research

The literature review for this research revealed four key issues, presented below:

- Construction is one of the most incident prone industries when it comes to safety. One of the most common situations where accidents to occur in the construction industry is when workers are moving about within the site (HSE, 2003a). The site superintendent plays a key role in maintaining a safe work environment for construction workers (Fung et al., 2005; Kines et al., 2010; Loosemore, 1998). Safety supervision is a crucial aspect of maintaining a safe work environment on any construction site (Hardison et al., 2014). Construction site superintendents also play

an important role to maintain quality control and acceptable levels of productivity (Lemna et al., 1986; Salminen and Saari, 1995).

- Several technological tools have been proposed to assist the site superintendent by monitoring location of construction workers to enable a safe construction environment (Aguilar and Hewage, 2013; Cheng and Teizer, 2013). Studies have shown that direct supervision of workers is one of the most effective methods of maintaining a safe construction site (Langford et al., 2000). Since it is not possible for the site superintendent to monitor all activities occurring on a construction site, electronic means to monitor workers has been proposed (Behzadan et al., 2008). Also, studies to monitor construction workers using video surveillance technology have shown limitations in worker identification and more so, it is based on ‘line-of-sight’ based technology that would not work when workers are not in the field view of the video camera (Teizer and Vela, 2009).
- The use of BIM in the construction industry is on the rise. The several benefits of using BIM in a construction environment have been documented including reduced costs, improved coordination and improved owner/contractor relationships, etc. (Azhar et al., 2008). The use of BIM is being increasingly mandated on construction projects, such as the mandate on all public procured construction projects by 2016, by the ‘UK Government Construction Strategy’ (Kumar, 2012). Moreover, the use of BIM has been demonstrated in several applications within the construction industry including better collaboration between stakeholders, collision detection between design disciplines, cost estimation, site planning and others (Boktor et al., 2014; Gray et al., 2013; Gu and London, 2010).
- RFID technology has been proposed as a ubiquitous method of tracking objects in the construction industry (Domdouzis et al., 2007). The use of RFID technology in construction has been validated to manage materials (Grau et al., 2009), tools (Goodrum et al., 2006), improve the supply chain of material delivery (Demiralp et al., 2012), for facility management (Ergen et al., 2007b; Ergen et al., 2007c), etc. New digital visualisation tools were created using RFID and 4D schedules

(Chin et al., 2008). Studies to use RFID technology to track construction workers on a construction site have also been proposed (Lee, et al., 2012).

This research developed a framework for site safety monitoring based on location tracking of construction workers in a virtual environment by combining RFID and BIM technologies. Literature has shown that RFID and BIM technologies will have a significant role in the future of the construction industry. RFID is a technology allowing real objects to be tracked in a physical space, whereas BIM technology can be viewed as a virtual representation of a physical space. This research proposes to combine the real world elements (i.e. construction workers) using RFID technology and representing them in a virtual environment using BIM. This combination has already been used for the purpose of tracking materials and has been proposed for tracking construction personnel (Zhou et al., 2012; Park and Kim, 2013). It is envisioned that the proposed framework will allow construction site superintendents to have an additional measure to monitor safety of construction workers within the site.

1.6 Research Approach

A detailed description of the approach taken for conducting this research is presented in Chapter 3. An overview of the research approach is presented in this section.

This is an exploratory study to develop a framework to monitor the location of construction workers to facilitate the construction site superintendent, for safety purposes. The framework is developed to combine RFID and BIM and represent the location of construction workers in real time on a construction site. Since the framework aims to enable the site superintendent in implementing site safety using RFID and BIM technologies, a review of literature was conducted for each of these items i.e. safety, construction supervision, RFID and BIM. Understanding causes of accidents in construction, construction company & construction superintendent roles in mitigating safety risks and technological tools being used to help maintain safety on construction sites were considered in the literature review process. The importance of knowing the location of construction workers for safety monitoring purposes was examined. Overview of RFID technology including the various ways it is being utilised was explored.

Specifically the use of RFID technology in the construction industry and construction safety was reviewed. Similarly an overview of BIM and its use in the AEC industry is discussed in the literature review. A rationale for combining RFID and BIM for the purpose of safety monitoring is presented in the literature review chapter.

Since this research is proposing a framework to enable construction supervision in implementing a safe construction environment, it is vital that views of construction superintendents are considered in developing the proposed framework. Nineteen construction site superintendents were interviewed to gather their opinions regarding the proposed framework and understand safety practices in the construction industry. The interviews discussed issues relating to the overall responsibilities of a superintendent, how they keep track of progress & quality of work, their views & experiences on maintaining safety, about the importance & methods of knowing the location of workers on a construction site and their views on the proposed framework for monitoring workers for safety purposes. The data from the interviews was analysed using inductive thematic analysis techniques as well as quantitative content analysis techniques. The results from the analyses were used to propose a conceptual framework for site safety monitoring based on tracking the location of construction workers on the site.

The conceptual framework was developed using qualitative data obtained by interviewing nineteen site superintendents. In an effort to validate the conclusions drawn from the interview data and the conceptual framework, an Internet survey was developed. The survey invited construction industry professionals to provide feedback about each aspect of the framework and about the overall framework itself. Survey respondents were asked to rate statements about the framework on Likert items ranging from ‘Strongly Agree’ to ‘Strongly Disagree’. The respondents were also provided with opportunities to provide written feedback expressing their thoughts about the framework. The data from the survey responses was analysed using descriptive statistics for the Likert items and deductive thematic analysis for the open-ended questions. The results from the analysis revealed that the conceptual framework proposed was a valid approach to enable the construction superintendent in maintaining safety on construction sites by monitoring the location of construction workers. Based on the quantitative and qualitative analysis of the

Internet survey data, no further modifications to the framework were necessary and the framework was considered validated.

A software prototype was developed to demonstrate that the proposed framework could indeed be implemented on a construction site, for safety monitoring. The software prototype was developed using ‘Identec RFID Solutions’ active RFID tags & readers in combination with ‘Tekla Structures’. A simulated construction site was used to evaluate the demonstrative software prototype using volunteer actors as construction workers. The evaluation was used for a few test case scenarios outlined in the framework. The evaluation revealed that the demonstrative software prototype would enable the site superintendent in implementing site safety using the proposed framework. The software prototype had a one-minute delay in demonstrating real time data regarding the movement of construction workers within the test site. However, it is anticipated that these delays can be significantly minimised in a working version of the software to implement the proposed framework.

1.7 Organisation of the Thesis

This thesis is organised into the following 7 chapters:

- **Chapter 1:** This chapter presents an overview of the research problem that is addressed in this thesis. The research aim and objectives are discussed. The scope of the research, rationale for conducting this research and the approach adopted to conduct this research is discussed. An overview of the results of primary data analysis is briefly discussed. An overview of the organisation of the various chapters in this thesis is also presented.
- **Chapter 2:** In this chapter, a critical review of the literature relevant to the focus of this study is discussed. These issues include site safety, the current state of the use of RFID technology and the current state of the use of BIM in the AEC industry. Issues that have been known to cause accidents in the construction industry, location monitoring for safety and accident mitigation strategies adopted by companies are discussed. The use of the RFID and BIM technologies in maintaining health and

safety on a construction site are explored. A rationale for combining RFID and BIM for safety purposes is presented.

- **Chapter 3:** An overview of the research methodologies available to conduct this research is discussed in Chapter 3. The use of the ‘Research Onion’ proposed by Saunders et al. (2009) in adopting the methodologies to conduct this research is discussed. Justifications for the choices made for each layer of the ‘Research Onion’ are presented. The data collection procedures and the associated data analysis procedures are discussed and justified.
- **Chapter 4:** The process of conducting semi-structured interviews with construction site superintendents is detailed in Chapter 4. The results from the qualitative analysis of the interview data are then discussed. The process of developing a conceptual framework to monitor the movement of construction workers using RFID and BIM for site safety purposes is finally presented.
- **Chapter 5:** An Internet survey was developed to validate the conceptual framework from the previous chapter. A quantitative analysis for the results from the Internet survey data of 130 respondents is presented. Qualitative data from open-ended survey questions supporting/refuting the quantitative data is discussed along with justifications for considering the framework being validated.
- **Chapter 6:** The penultimate chapter presents an overview of the development of the demonstrator software prototype for implementing the framework to monitor the movement of construction workers using RFID and BIM. The hardware and software solutions used in the creation of the software prototype are discussed. Descriptions of implementing selected scenarios using the framework in a simulated construction environment are discussed.
- **Chapter 7:** An overall summary of the research presented in this thesis is discussed in the final chapter. A brief summary of the processes undertaken in the conduct of this research and the findings of the research are discussed. The contribution to knowledge

of this research from both an academic and an industry perspective is discussed. The limitations in the pursuit of this research are deliberated, in addition to a discussion regarding future research that may be conducted in this area.

1.8 Summary

This chapter presented a brief introduction to the issues that are central to this thesis, namely site safety monitoring and the use of RFID and BIM technologies as a solution to assist the site superintendent. The research aim and objectives were presented and the rationale for proposing this research within the context of the research currently being conducted is argued. The approach adopted for conducting this research was described. An explanation about the structure used in organising this thesis was offered. The next chapter presents a critical review of the literature concerning the major issues that are the focus of this study.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

The previous chapter presented a brief introduction to the issues considered for conducting the research as part of this PhD thesis. The aim and objectives of the study were discussed. A brief rationale for conducting this research and the approach adopted at various stages of the research were presented. A brief outline of the various chapters was discussed. In this chapter, a critical literature review of issues relevant to this thesis including safety in construction, construction supervision, RFID technology, BIM technology and the use of visualisations in construction are presented. The use of RFID and BIM for safety applications is discussed, in the light of differences between the literature and the current study. The rationale for conducting this research is also presented.

2.2 Health and Safety Issues in Construction Site Safety

There were an average of 1089 fatalities that occurred annually in the US construction industry between 1992 and 2012. During the same time period the construction industry had an average of approximately 19% of all work place-related fatalities, as shown in Figure 2.1 (Bureau of Labor Statistics, n.d.). These statistics make construction one of the most dangerous professions in the US and is consistently in the top five most dangerous professions in terms of per capita fatalities.

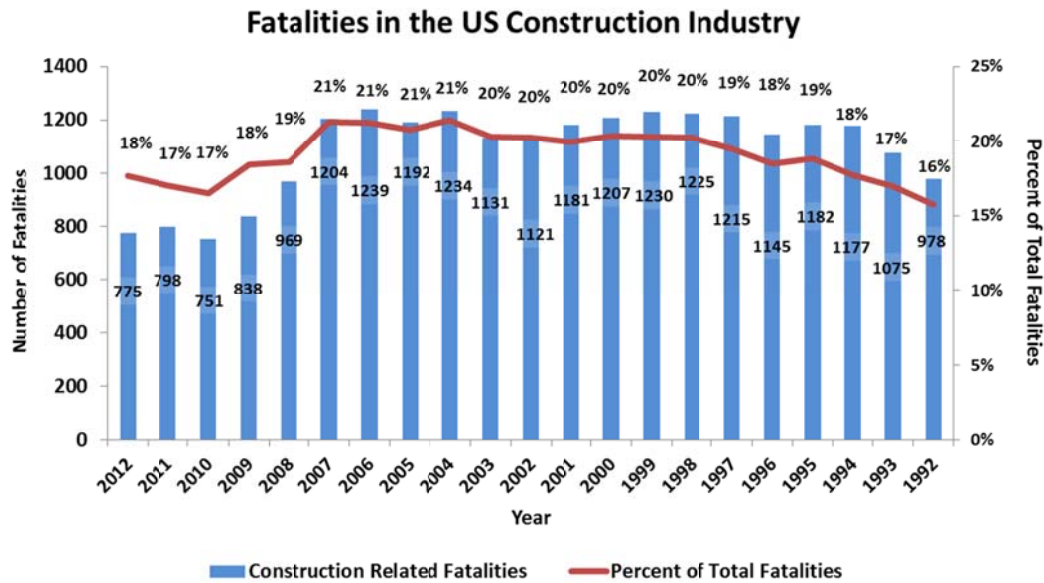


Figure 2.1: Accident data for the US Construction industry. (Bureau of Labor Statistics, n.d.)

Construction site safety is a very complex yet expensive issue (Li and Poon, 2013). Lapses in safety in the construction industry are linked to major economic losses (Cheng et al., 2011). On the other hand, a successful safety record contributes to higher morale, profitability, turnover and margins (De la Fuente et al., 2014). Moreover, a successful safety record can serve as a sustainable competitive advantage by reducing the cost of insurance for the company (Rechenthin, 2004). To understand the issue of safety in the construction industry, it is relevant to understand the various reasons accidents have been known to occur.

2.2.1 Overview of Issues Affecting Construction Safety

The construction industry encompasses many trades such as ironworkers, electricians and plumbers, etc. The safety outcomes for each of these professions vary based on the risks inherent with the working conditions and hazardous nature of the tasks being performed (Cigularov et al., 2013). The working conditions on a construction site are also constantly changing and pose an inherent safety risk (Chae and Yoshida, 2010). This unpredictable nature of construction tasks increases the risk of workers being exposed to a hazard or

hazardous condition (Mitropoulos et al., 2005). Some construction project types such as hydro power projects and nuclear power projects are inherently more dangerous due to the site conditions and materials involved (Zhou et al., 2014; Li and Wu, 2013). Hinze & Raboud (1988) suggest that on very large projects there may be too many workers on site for everyone to know each other and the resulting alienation can cause an increase in safety incidents. Guo et al. (2013) also agree that due to the presence of many workers on site, presence of multiple large & heavy equipment and complex management structures, large construction projects have higher accident rates.

In 2009 the UK governments' Health and Safety Executive (HSE) published a comprehensive two-phased study to investigate the underlying causes of accidents in the construction industry (HSE 2009a; HSE 2009b). The findings from both studies revealed that multiple factors are responsible for accidents to occur in the construction industry. These factors include:

- Lack of attention paid to safety related issues by corporate leadership and lack of safety issue consideration at the contractual strategy adoption stage of the project.
- Inadequate considerations to safety issues at the site management level of the project including competence and training of the workers, design and selection of construction equipment, site layout and housekeeping, supervision and monitoring issues, risk assessment and planning issues, etc.
- At the worker level, lack of competence, training, motivation communication, cooperation and planning on behalf of the participants contributed to accident causation. Workplace ergonomics, hazards, design suitability and usability of hardware equipment were also listed as factors.

Construction workers often work with specific deadlines on tasks and are frequently working with their bodies in awkward positions (Gillen et al., 2002). The pressures of keeping a construction job on schedule have been a known cause for the occurrence of accidents (Schneider and Check, 2010). The pressures of maintaining productivity and completing tasks on schedule have been known to affect foremen's behaviour in terms of how strictly they adhere to safety regulations (Kaskutas et al., 2013). Similarly, working overtime to meet the demands of the schedules can have adverse effects for the health and

safety of the workers (Goldenhar et al., 2003). Rework on a construction project is when completed work has to be replaced due to changes in design or for not meeting quality standards. Rework on construction projects has been correlated with higher incidences of injuries on site. Rework applies pressure to catch up with the original schedule due to lost production and schedule delays. This in turn puts pressure on workers and management to work faster and longer, leading to higher safety incidents (Han et al., 2013).

Optimism bias is a concept wherein a subject feels that negative things are less likely to happen to them than the average person. Optimism bias exists among construction workers with regards to their personal safety on site and can lead to complacency when implementing safety management plans on the construction work site (Caponecchia and Sheils, 2011). There is often disagreement among construction personnel about the factors most influencing safety on construction sites (Yu et al., 2014). Two common causes for accidents in the construction industry are ‘Unsafe Acts’ by workers and ‘Unsafe Conditions’ on the site (Heinrich et al., 1980). It has been noted that unsafe conditions are easily identifiable in the event of an accident or a near miss accident and proper precautions are taken to avoid those in future (Joyce, 2008). However, it has also been identified that more accidents occur due to unsafe acts by workers and that it is harder to identify unsafe acts to prevent accidents (Shin et al., 2013). There also exists a ‘machismo’ attitude among construction workers, who have also been identified as having low levels of education, which contributes to the occurrence of these ‘Unsafe Acts’ (Sousa et al., 2014).

The fragmented nature of the construction industry has also been identified as issue that contributes to the unfavourable safety outcomes in the construction industry (Sousa et al., 2014). The fragmentation issue is identified at not only the subcontractor level but also at the design and contractual level depending on the type of project delivery method adopted. For example, Gambatese et al. (2005) identified that integrated project delivery methods such as ‘Design-Build’ produced better outcomes for safety as opposed to the traditional delivery method of ‘Design-Bid-Build’. This is largely due to the interaction between the construction and design teams early on in the process where the contractor may alert the designer about safety hazards, such as a specific design detail and the

designer can modify the design to minimize the safety risk. A further discussion regarding the role of design in construction site safety is discussed in a Section 2.2.4 within this Chapter.

Other issues causing accidents in the construction industry include lack of proper training and how training alone is not enough to ensure that workers have a proper knowledge of executing construction tasks (Dong et al., 2013). The cost and time for implementing proper protection mechanisms may lead to complacency and accidents, especially in smaller construction firms (Holmes et al., 1999). Studies also indicate that smaller sub-contractors may not have full-fledged safety training programs for their workers (Goldenhar et al., 2001). Language barriers within the workers exist in the US construction industry due to the presence of about 2.2 million Hispanic workers on construction sites (Gittleman et al., 2010; Evia, 2011). These language issues can cause potential communication gaps resulting in safety incidents. It is commonplace in the construction industry for workers to do overtime. The use of drugs and alcohol among construction workers has been identified as one of the issues in the cause of accidents on construction sites (Schofield et al., 2013). Fatigue and increase in ambient temperature have also been linked to high incidence of accidents in the construction industry (Rowlinson et al., 2014). High turnover of workers has been known to cause accidents in the construction industry (Hinze, 1978). Overcrowded workplaces in construction can contribute to unsafe construction environments (Gittleman et al., 2010).

2.2.2 Role of Management in Construction Safety

Studies have shown that commitment towards safety from upper management is one of the most important aspects in maintaining a safe work environment (Priyadarshani et al., 2013). Rowlinson et al. (2004) identify the role of management as an external input that can affect the safety outcomes on a construction site. Baxendale and Jones (2000) argue that construction companies use a variety of communication methods to ensure the implementation of a safety management plan, including visual behaviour and face-to-face discussions. In the UK, as part of the Construction Design and Management regulations (CDM), the principal contractor is responsible to ensure that they are taking reasonable measures to maintain health and safety on a construction site starting from a pre-tender

safety plan and continuing on to actual construction practices on the site (Baxendale and Jones, 2000). Mandatory regulations such as the CDM, do not exist in the United States (Gambatese et al., 2005).

Management attitudes, collective values and individual attitudes often interact with each other and play a role in the existing safety environment on a construction site (Törner and Pousette, 2009). Clarke (1999) suggests that “‘*Safety culture*’ may be perceived as a subset of organisational culture, where the beliefs and values refer specifically to matters of health and safety”. Clarke (1999) found that while groups within the organisation agreed about the importance of safety, they each had unrealistic perceptions about others regarding safety. The perception of safety climate within a construction site can vary between construction workers, field superintendents and managers (Gittleman et al., 2010). Dedobbeleer and Beland (1991) argue that in a construction organisation, management should publicise the importance of safety to workers and must also involve the workers in developing safety plans in an effort to improve the safety climate within the organisation. The ‘safety climate’ in an organisation is the degree to which the employees give true importance to safety performance. The measurement of ‘safety climate’ within a construction organisation is a departure from measuring statistical data such as accident frequency and instead focuses on measuring the commitment within the organisation to improve safety outcomes (Flin et al., 2000). Empirical links between safety climate and safety behaviour have been found (Cooper and Phillips, 2004). Cooper and Phillips (2004) argue that the relationship between management and workers about safety is a complex and posit that the true benefits of understanding that relationship could lead to meaningful benefits for all stakeholders. Consistently enforcing safety plans on a construction site have shown positive results in establishing a safe site (McDonald et al., 2009). Some construction companies have tried to incentivise good behaviour on part of construction workers; however this has produced mixed results in terms of improving the actual safety outcomes on a construction project (Teo et al., 2005). Incentive programs are inherently limited by rewarding fewer or no incidents rather than rewarding safe behaviour. However, construction firms that provided smaller value but frequent incentives as well as firms that rewarded entire crews rather than individual workers were successful in using the incentive programs to minimize safety incidents (Hinze, 2002).

A review of literature has shown that management plays a crucial role in the safety climate, perceptions and outcomes within an organisation. It is acknowledged that management is important in maintaining and improving safety conditions within the site. However, since this study is concerned with developing a framework for construction worker monitoring by the site superintendent for safety purposes, a detailed analysis of managements' role regarding this issue is considered outside the scope of this study. The superintendent is management's representative on the construction site, enforcing safety apart from performing other duties. The role of the construction superintendent in the context of safety is examined in the next section.

2.2.3 Role of Site Superintendent in Construction Safety

The task demands of workers must match their skill levels in order to maintain productivity as well as safety (Mitropoulos and Cupido, 2009). The involvement of construction workers in the development and implementation of a safety management plan is essential (Dedobbeleer and Béland, 1991). However, the role of the construction superintendent in the implementation of the safety management plan is significant and cannot be discounted (Fung et al., 2005; Gillen et al., 2002). A well formulated construction safety plan for a project is only the first step in the implementation of a safe work environment and in fact the plan's success is driven more by the implementing superintendent on the construction site (Agrilla et al., 1999). Agrilla et al., (1999) argue that the implementation, checking and corrective actions are a continuum of the safety process, preceded by the development of the safety plan. Studies have shown that superintendents verbally communicate with construction workers several times during a typical day (Kines et al., 2010). Kines et al. (2010) have also shown that construction superintendents can be coached to improve the safety levels on construction site. Construction superintendents are often the first line of managers in implementing a safe work environment and occasionally find themselves in compromising situations where they have to choose between sacrificing productivity rates or turn a blind eye to unsafe practices (Langford et al., 2000).

Lingard and Rowlinson (1997) propose implementing behaviour-based safety management programs in the construction industry. Direct observation of workers in their

natural work environment is central to the evaluation of the success of such systems (Lingard and Rowlinson, 1997). In their ‘Framework for Managing Construction Safety’, Teo et al., (2005) identify the role of superintendents and safety officers as a key issue and propose the use of performance measurement approach rather than a compliance approach towards worker safety. Studies have shown that when workers feel like they can communicate with their superintendents about safety-related issues, the safety outcomes for construction workers can be improved (Cigularov et al., 2010). Mentoring has been known to play an important role in regards to safety coaching in the construction industry; however the constant changing nature of construction tasks and the temporary nature of the relationship between the mentor and mentee in the construction industry can adversely affect this coaching process (Hoffmeister et al., 2011).

The human characteristics of workers, superintendents, combined with the often chaotic nature of the construction sites, where workers from different trades are working simultaneously on tasks that have different hazards associated and environmental factors, have each been identified as contributing factors for causing accidents (Sousa et al., 2014). Hinze (1987) argues that the safety outcomes of a construction project depend to some extent on the capabilities of the superintendent. Hinze further posits that when a superintendent is well organised and is running a well-coordinated site and keeps the project on schedule, they are more likely to have positive safety outcomes. This research will examine the role of the construction superintendent and consider how monitoring the movement of workers on the site may enable the superintendent for health and safety purposes.

2.2.4 Role of Design in Construction Safety

In 2003 the UK governments’ HSE commissioned a study to investigate the causes of accidents in the construction industry, which was conducted by Loughborough University (HSE, 2003a). After studying 100 accidents, researchers concluded that in at least half of the cases accidents could have been mitigated with an alternative design (HSE, 2003a). In the same report findings from focus groups with industry professionals found that clients and designers “...give insufficient consideration to health and safety, despite their obligations under the CDM regulations” (HSE, 2003a, p. vii). Construction Design and

Management regulations (CDM) are issued by the UK government's HSE to the various stakeholders of a construction project. In its two-phased study conducted in 2009 to identify the main causes of construction accidents, the HSE found that designers could have played a significant role in preventing 37 of the 73 accidents investigated as part of the study (HSE, 2009a, 2009b). The reports blamed the designers for issues such as poor communication between parties, not considering existing site conditions or adjacent structures and their impact on safety, not understanding construction processes, not considering access routes to the site, not considering procurement routes for materials, etc. While the CDM regulations were introduced to reduce the number of accidents in the UK construction industry, there have been challenges in reaping the full benefits of the regulations, as there is on-going some debate within the industry about roles and responsibilities of various stakeholders (Beal, 2007). The appropriate role and amount of interaction between the client, designer and contractor as it relates to safety, is still being argued (Baxendale and Jones, 2000; Beal, 2007). Currently, the CDM guidelines are under further review by the HSE and are expected to be further modified in the coming years (Warburton, 2014).

The findings from UK HSE are similar to the findings of American researcher Behm (2005), who found multiple examples of how fatal accidents could have been likely prevented by designers that paid closer attention to the safety aspects of their designs, by studying 500 accidents. Behm's (2005) suggestions for designers included designing special connections or holes in members at elevated places to allow workers to be tied off, re-routing power lines during construction, provisions for permanent guardrails at elevated places, considering the traffic patterns on the construction site to include the design of temporary access during construction, etc. The standard practice of design in the AEC community in the US does not include design regulations such as those found in the CDM in the UK (Gambatese et al., 2005). OSHA places the primary and legal responsibility of worker safety on the contractor, instead of all stakeholders of a construction project. In the absence of design regulations, Gambatese and Hinze (1999) provided a detailed list of over 400 'design suggestions' that are aimed at designers playing an active role in preventing construction accidents. These design suggestions include issues such as minimising or eliminating the amount of work done in elevated

spaces, increasing the amount of construction that can be done offsite, designing with sufficient clearances from overhead power lines, etc. The lack of standard design guidelines for safety in the US is due in part because of the lack of education on safety issues within the design community and the liability concerns of designers to formally address issues related to construction safety in their designs (Gambatese et al., 2005). In the US, regulations that formally charge designers to consider the safety aspects of their designs, as demonstrated by the CDM regulations in the UK, seem to be an obvious shortcoming.

Literature has shown that design teams are uniquely situated in the construction of a facility to pay particular attention to safety aspects of their designs. However, as presented in all of its studies, the HSE (2009a, 2009b, 2003a) acknowledges that design alone cannot prevent accidents from occurring in the construction industry. In the conclusion of two independent studies, the HSE found that the most common situation where accidents occur, was during the movement of workers within the construction site for accessing materials or during assessing or leaving the site (HSE, 2003b). The report does not suggest that movement of workers alone is an indication of an inherent safety threat, but merely a situation where safety incidents seem to occur more often. Since construction workers would need to move about within the site, regardless of the design of a facility, the role of design in site safety is not considered in this study. While the importance of design in the overall safety aspect of the construction project is acknowledged, this research will consider the supervision aspects on the construction site and how the superintendent can be enabled in monitoring the safety of workers. Therefore safety related issues from a facility designer perspective were not extensively examined.

2.2.5 Technological Tools to Implement Construction Safety

The United States National Academy of Engineering has identified restoring and improving the countries urban infrastructure as a grand challenge in the 21st Century (National Academy of Engineering, n.d). Specifically, they advocate the role of automation in improving the construction industry (Brilakis et al., 2011). The adoption of automated tools and technologies is already on the rise in the construction industry (Teizer et al., 2010b). Examples include the use of laser scanners for collecting as built-

drawings (Bosché et al., 2014), the use of GPS for automated site grading equipment (Baertlein et al., 2000), use of robots for construction activities (Hatao et al., 2014), use of photogrammetry for measurement (Aydin, 2014) etc. Automated data collection methods to monitor and improve construction safety are already in use in the construction industry (Cheung et al., 2004). GIS, BIM and 4D schedule visualisation technologies are being used for safety planning in the construction industry (Bansal, 2011). The use of laser scanning equipment placed in the cabs of heavy equipment is being explored to minimise blind spots (Teizer et al., 2010b). The use of BIM models and automated safety checks of the model using OSHA regulations has been proposed (Zhang et al., 2013). Comprehensive systems to monitor safety on multiple projects was developed using several information and communication technologies (Aguilar and Hewage, 2013). Simulations of construction activities using virtual prototyping methodology for identifying unsafe conditions on construction sites has been proposed (Guo et al., 2013). The use of virtual reality in training construction workers for safety purposes has been proposed (Sacks et al., 2013b). The use of GPS devices is advocated for the creation of a concrete bucket collision warning system in a concrete dam construction project (Wu et al., 2013).

Literature has shown that the use of technological tools to improve safety outcomes in the construction industry has been demonstrated over the past two decades. The use of technology for managing and improving construction safety is on the rise in academic research as well as in practice.

2.2.6 Tracking Location of Construction Workers for Safety Purposes

The 2003 HSE (2003b) study concluded that the number one situation where accidents occur in the construction site is during the movement of workers within the site. There could have been further conditions that lead to these accidents such as falling from heights or tripping over materials, which was not cited in the HSE report. Nevertheless, it is pertinent to this study to note that movement of workers within the construction site can lead to accidents. This study considers if knowing the location of workers within the construction site can enable the superintendent in making safety decisions.

The same HSE (2003b) report also cited poor supervision as one of the reasons for accidents occurring on the construction site. Research presented earlier indicates that one of the duties of superintendent is to physically monitor the work occurring on the construction site. It may be concluded that it would be difficult if not impossible for the superintendent to monitor all workers at a given time on the construction site. Therefore any means that can allow the superintendent to know the location of workers within the construction site can be beneficial. Use cases of tracking construction workers within the site, from a safety perspective have been found in the construction industry news. The Ekahau (2009) company demonstrated the use of wireless tags and readers combination to track workers in the construction of tunnels in Spain. Similarly, Northern Light Technologies implemented the use of active and passive RFID tags in the construction of a 4.8km tunnel in Brisbane, Australia (Friedlos, 2008). DPR Construction Company used passive RFID tags and readers at key locations to track the movement of workers, to automate the head count process at a 900,000 SqFt construction site in California (Abaffy, 2013). In the case of DPR construction, they used a vendor who was also able to integrate the tag information into the project building information model. Grunley Construction in the US used an RFID based solution to track its workers on their university construction projects (Constructech, 2012). In all of the use cases of tracking construction workers on site, implementation details were not discussed in detail as these were found in news and magazine articles. However, these news articles suggest that the use of technological tools to track construction workers for safety purposes is being investigated in the construction industry.

Proposals pushing the use of technology to track construction workers on a site are not new in construction research. The use of tracking technologies for maintaining site safety on construction sites has been proposed by academic researchers (Carbonari et al., 2011; Teizer et al., 2013; Wu et al., 2010b). Carbonari et al. (2011) suggest that construction projects should take advantage of advancements in sensing technologies to locate workers who enter hazardous areas. They demonstrated an RFID based safety management tool that tracks and alerts a construction worker when they enter a predefined dangerous area. Jiang et al. (2014, p. 2) encourage the use of real time location based monitoring of construction workers for conducting safety risk assessments, as evidenced by the

statement “*Overall, the development of automatic monitoring technology, especially the real-time location technology for individuals, provides great feasibility for implementation of real-time safety risk assessment*”. Teizer et al. (2013) similarly argue that location information of workers can be used in safety training applications. Construction workers were tracked in a real-time simulated environment to demonstrate how workers can be warned when their proximity is too close to a hazardous area. Wu et al. (2010b) propose the use of real-time tracking technologies be used to study precursors to accidents and near miss accidents to prevent real accidents from occurring in the future.

Lu et al. (2011, p. 105) suggest “*By using RFID technology, an affordable employee tracking system can be developed to provide real-time information, which is critical for construction safety*”. An investigation of accident data suggests that 25% of all construction fatalities are related to proximity of workers to construction equipment (Teizer et al., 2010a). Ultra wide band technology was successfully used in a large open construction site to track location of resources within the site, including equipment and workers (Cheng et al., 2011). RFID tags were used in association with Zigbee networks, another radio frequency based sensing technology, to check if construction workers were wearing their personal protection equipment (PPE) (Barro-Torres et al., 2012). The PPE's themselves were tagged with the RFID equipment and thus enabled the contractors to verify that all the necessary PPE's were present as they passed through check points where RFID readers were placed (Barro-Torres et al., 2012). Vision based tracking technologies (i.e., video cameras) can be used to identify the presence of construction workers. However, this is not practical to use inside a building under construction as it is a ‘line of sight’ based technology and moreover cannot be used to identify individual construction workers (Brilakis et al., 2011). Furthermore, since the environmental conditions on a construction site are constantly shifting, physical obstacles may hinder ‘line of sight’ based technologies for worker tracking.

Locating workers in areas where they are not trained to be present or when dangerous conditions exist in an area are addressed by the studies that have considered location monitoring for safety purposes (Cheng and Teizer, 2013; Park and Kim, 2013). However,

literature has shown that the accidents on construction sites occur due to several factors including inadequate design considerations, poor safety culture within the company, ineffective training provided to workers, lacking supervision on site, attitude of individual workers on site, etc. In the consideration of unsafe acts by workers, location monitoring allows the safety manager or superintendent to consider a situation where a safety incident might occur. Specifically, what the worker is doing at that location has not been addressed in the studies found in the literature. Several studies suggest that safety must be considered from a comprehensive lens (Coble, 2000; Hislop, 1999; HSE, 2003a; McDonald et al., 2009). Therefore the role of location monitoring in maintaining site safety has to be considered a small part of the overall strategy to maintain a safe work environment.

An analysis of the literature suggests that experts agree that knowing the location of construction workers on site, in real time is important for successful safety management. Use cases of tracking the location of workers for safety purposes have been found in various types of construction projects. The use of RFID and similar wireless technological tools was proposed and demonstrated for safety management systems. The issue of location tracking for safety purposes is further examined in Section 2.9 of this thesis.

2.3 Overview of Location Tracking Technologies

Various location-tracking technologies are currently available in the market. These include Bluetooth, Global Positioning Systems (GPS), Indoor GPS, Infrared (IR), RFID, Wireless Local Area Network (WLAN) and Zigbee. A brief description of these technologies is presented in this section.

- **Bluetooth Tracking:** Bluetooth technology relies on wireless signals sent from a Bluetooth enabled device such as mobile phone to a receiver at a known location (Shen et al., 2008). The signal strength is used in determining the location of the signal-sending device. The principles of Bluetooth tracking are similar to a WLAN tracking. Some of the drawbacks for Bluetooth technology include delays in interpretation when several tags are located in a single area/zone and the tags do not

have on-board memory for storing any information (Aparicio et al., 2008). Any technology relying on signal strength to determine location has accuracy issues as these signals are susceptible to interference from surrounding objects (Montaser and Moselhi, 2014).

- **GPS Tracking:** GPS tracking is based on a GPS enabled device communicating with a network of satellites in space to determine the location of the device (Parkinson and Spilker, 1996). This type of tracking is suitable for outdoor construction projects only since a GPS enabled device indoors would not have a line-of-sight to satellites in space. It is possible to use this type of tracking in combination with other tracking technologies to locate entities on a large construction project (Andoh, 2012).
- **Indoor GPS:** Indoor GPS is a line-of-sight based tracking technology. Similar to GPS satellites, multiple transmitters act as satellites and send a laser signal to receivers in the field of view. The receiver detects the signal from each of these transmitters and uses triangulation methods to identify its location in space (Maisano et al., 2008). This tracking technology has limitations since in an active construction environment the environmental conditions, size of the site and the physical space are constantly evolving (Hinze and Raboud, 1988). This dynamic nature of the construction site makes it harder to use indoor GPS for location tracking. Furthermore, the line-of-sight between receivers and transmitters can be blocked by other objects such as construction materials and equipment.
- **IR Tracking:** IR tracking requires line of sight between the tag and the reader. An infrared badge or a tag sends a beacon that is picked up by a receiver that is placed at known locations. The beacon signal is used to interpret the location of the badge or tag in an IR based tracking system (Bahl and Padmanabhan, 2000). Therefore the use of IR for location tracking has similar limitations as indoor GPS, on a construction site where environmental conditions are constantly changing. The line-of-sight limitations discussed for indoor GPS are valid for IR tracking as well.

- **RFID Tracking:** RFID tracking is based on a tag sending a radio signal to a receiver. The signal strength of the tag can be used to interpret the location of the tag. The tag and receiver combinations require an extensive network to be functional in a construction environment. Customisation of the tag-reader network is also required to use this technology (Li and Becerik-Gerber, 2011). Relying on signal strength from the tag to interpret the location of a tag is not always very accurate as radio signals are reflected due to adjacent electromagnetic surfaces such as metals, walls, etc. (Montaser and Moselhi, 2014).

- **WLAN Tracking:** A wireless device communicates with a Wi-Fi access point using radio signals. The strength of the radio signals is used to interpret the location of the wireless device in WLAN location tracking system (Behzadan et al., 2008). This technology is generally considered expensive and is suitable for indoor tracking situations. An extensive network of Wi-Fi access points is needed for utilisation in an outdoor environment. Delays in interpreting location are also noticed when numerous devices are connected to a Wi-Fi access point and the number of devices that can be connected to a Wi-Fi access point is also limited, based on the particular system selected (Shen et al., 2008).

- **Zigbee Tracking:** Zigbee based tracking is similar to RFID tracking in that a tag sends a signal to a sensor and the sensor interprets the signal strength to identify the location of the tag. However, an extensive network of Zigbee sensors must be deployed to accurately interpret the location of the tag (Shen et al., 2008). In a construction environment that is constantly changing, such a network may be difficult to establish.

2.4 Overview of RFID Technology

RFID is a wireless sensor technology that is based on the transmission and decoding of radio waves. The technology itself has its roots in the research done by Michael Faraday as well as in the research done between 1900 and 1940 on radio and radar technologies (Mickle et al., 2010). This technology has been in popular use at least since the Second World War when British aircrafts used this technology to differentiate between enemy

and friendly aircrafts returning to their base stations (Domdouzis et al., 2007). The use of RFID technology as an antitheft measure in the retail sector was introduced in the 1960s where the tags at the time could only indicate their presence (Landt, 2005). Considerable research in the area occurred during the 1970s by reputed private and public sector entities including ‘Los Alamos Laboratory’, ‘General Electric’, ‘Westinghouse’, ‘The Port Authority of New York and New Jersey’ and ‘Phillips’ (Landt, 2005). This research resulted in the widespread adoption of RFID technology during the 1980s and 1990s. Today, RFID technology is used to track objects, livestock and people. It is plausible to think that this technology will fully replace the use of barcode technology for tracking purposes (Wu et al., 2006).

A typical RFID system and the associated communication protocol is presented in Figure 2.2 (Adapted from Tedjini et al., 2005). The main components of an RFID system include a host computer (not shown in Figure 2.2), an RFID tag and an RFID reader along with an antenna (identified as the ‘Base-Station’ in Figure 2.2). When the tag enters the electromagnetic zone of the base station, the tag receives and responds to an activation signal from the reader. The response from the tag is read by the reader’s antenna. The data is decoded by the reader and transmitted to the host computer for further processing. The system described in Figure 2.2 is a typical passive RFID tag/reader system.

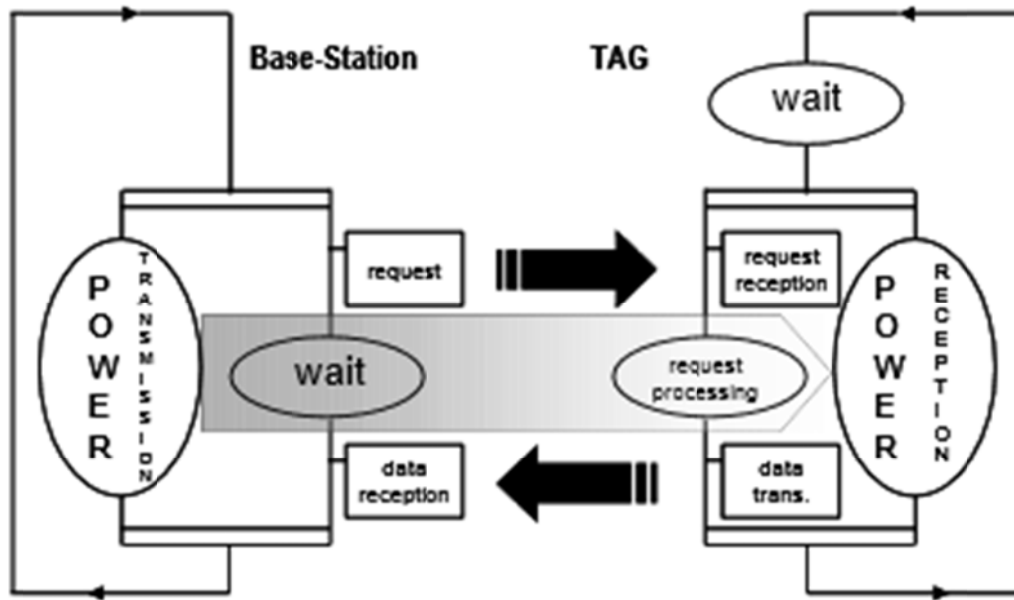


Figure 2.2: Schematic RFID system and communication protocol (Adapted from Tedjini et al., 2005)

RFID tags can be broadly classified into active and passive tags, as shown in Figure 2.3 (Adapted from Atlas RFID, n.d). A passive tag does not have a power source and it is activated when it is within range of the electromagnetic field of the reader. The range, over which a passive tag may be read, is relatively small, typically three meters or less. Passive tags are relatively cheap and also have a small physical size ranging anywhere from a sticker to a credit card. Passive tags work best when the items tagged have to move through fixed choke points so that the tags have to enter/exit through a specified area where the readers and antenna would be placed with their electromagnetic fields. Passive tags are typically found in the retail sector to prevent theft, in supply chain management, libraries, passports, subway cards and other applications. In each of these examples, the tag, which may attached to merchandise or a library book or a passport, have to go through a choke point such as the entrance to a store or library or a passport control check point. Hence, the passive tag is suitable for such applications.

	ACTIVE RFID	PASSIVE RFID
<i>Power</i>	Battery operated	No internal power
<i>Required Signal Strength</i>	Low	High
<i>Communication Range</i>	Long range (100m+)	Short range (3m)
<i>Range Data Storage</i>	Large read/write data (128kb)	Small read/write data (128b)
<i>Per Tag Cost</i>	Generally, \$15 to \$100	Generally, \$0.15 to \$5.00
<i>Tag Size</i>	Varies depending on application	"Sticker" to credit card size
<i>Fixed Infrastructure Costs</i>	Lower – cheaper interrogators	Higher – fixed readers
<i>Per Asset Variable Costs</i>	Higher – see tag cost	Lower – see tag cost
<i>Best Area of Use</i>	High volume assets moving within designated areas ("4 walls") in random and dynamic systems	High volume assets moving through fixed choke points in definable, uniform systems
<i>Industries/Applications</i>	Auto dealerships, Auto Manufacturing, Hospitals – asset tracking, Construction, Mining, Laboratories, Remote monitoring, IT asset management	Supply chain, High volume manufacturing, Libraries/book stores, Pharmaceuticals, Passports, Electronic tolls, Item level tracking

Figure 2.3: Active RFID vs. Passive RFID tags, adapted from Atlas RFID (Atlas RFID, n.d.)

An active RFID tag contains an autonomous power source in the form of a battery and transmits a signal at specified intervals and that signal is interpreted when it is within range of a reader. These tags can have long range of communication of more than one hundred meters. Active tags are more expensive than passive tags and can cost anywhere from \$15 to \$100. RFID technology is popularly used in automotive, construction, mining, asset tracking, healthcare and other industries. Active tags are useful in applications that do not rely on the tag having to go through a zone where a reader is located. For example, in the case of construction, tools on the construction site were tracked using active RFID tags (Goodrum et al., 2006). Since tools can be used in any location within the construction site, an active RFID tag is better suited for the purpose.

Similarly in the mining industry, RFID tags are used to track material mined, equipment and workers (RFID Journal, 2013). Here again, the tagged resource could be located anywhere on the site of the mine, depending on the context such as workers at different locations within the mineshaft, making the use of active RFID appropriate.

RFID technology is transmitted across several different frequencies, depending on the type of system, country and application. The frequency ranges of RFID technology are shown in Figure 2.4 (Adapted from Wyld, 2006) and described below:

- **Low Frequency (LF) 125 to 134 KHz band:** LF systems have a relatively short range of up to 18-inches and have low reading speed associated with them. They are relatively inexpensive and can be read through liquids. They are typically used for inventory control, animal identification, access control and antitheft systems.
- **High Frequency (HF) 13.56 MHz:** HF systems have a medium range of between 3 feet and 10 feet and have medium reading speed. These tags can be read through liquids but do work well near metal objects. They are typically used in access control, smart cards, library books, airline baggage tracking and similar situations.
- **Ultra High Frequency (UHF) 850 to 950 MHz:** UHF systems have a range of 10ft to 30ft and are relatively expensive tags. They have high reading speeds and have reduced likelihood to cause signal collision. They do not work well in moist environments and are prone to interference from metals. UHF RFID systems are used in item management and supply chain management situations.
- **Microwave Frequency 2.45 to 5.8 GHz:** These systems have a medium range of more than 10ft and have very high read rates. They are typically used in tollbooth systems and to monitor railroad cars.

Frequency band	System characteristics	Example applications
Low (LF) 100-500kHz (typically 125-134KHz worldwide)	Short read range (to 18 in.) Low reading speed Relatively inexpensive Can read through liquids Works well near metal	Access control Animal identification Beer keg tracking Inventory control Automobile key/ anti-theft systems
High (HF) (typically 13.56MHz)	13.56 MHz frequency accepted worldwide Short to medium read range (3-10 ft.) Medium reading speed Can read through liquids/works well in moist environment Does not work well near metal Moderate expense	Access control Smart cards Electronic article surveillance Library book tracking Pallet/container tracking Airline baggage tracking Apparel/laundry item tracking
Ultra High (UHF) 400-1000 MHz (typically 850-950 MHz)	Long read range (10-30 ft.) High reading speed Reduced likelihood of signal collision Difficulty reading through liquids Does not work well in moist environments Experiences interference from metals Relatively expensive	Item management Supply chain management
Microwave 2.4-6.0GHz (typically 2.45 or 5.8GHz)	Medium read range (10+ feet) Similar characteristics to UHF tags, but with faster read rates	Railroad car monitoring Toll collection systems

Figure 2.4: Frequency ranges of RFID systems and its applications (Wyld, 2006)

A typical assembly of active RFID tracking mechanism is shown in Figure 2.5. The tags transmit information to the antenna of the reader. A network of numerous readers can be connected in series and located at various choke points within an application and is referred to as ‘Daisy Chaining’ (Eberle et al., 2004). The information from the readers is transmitted to a wireless device or a host computer. The host computer receives and stores the tag read data directly into a database. Since tag information is collected in real-time from multiple readers or a single reader within the network of readers, location information about the tag and therefore whatever the tag is attached to can be approximated. Active RFID tags also provide the ‘Received Signal Strength Information’ (RSSI). The RSSI is a numerical value that indicates the strength of the signal to the reader, based on its proximity to the reader. However, since RFID tag signal can be distorted due to reflection and interference issues with metal objects, the RSSI number from a single read by itself is not sufficient to estimate the distance of a tag from the

reader (Benkic et al., 2008). This issue of tracking the location of tags in space is addressed in a later section within this chapter.

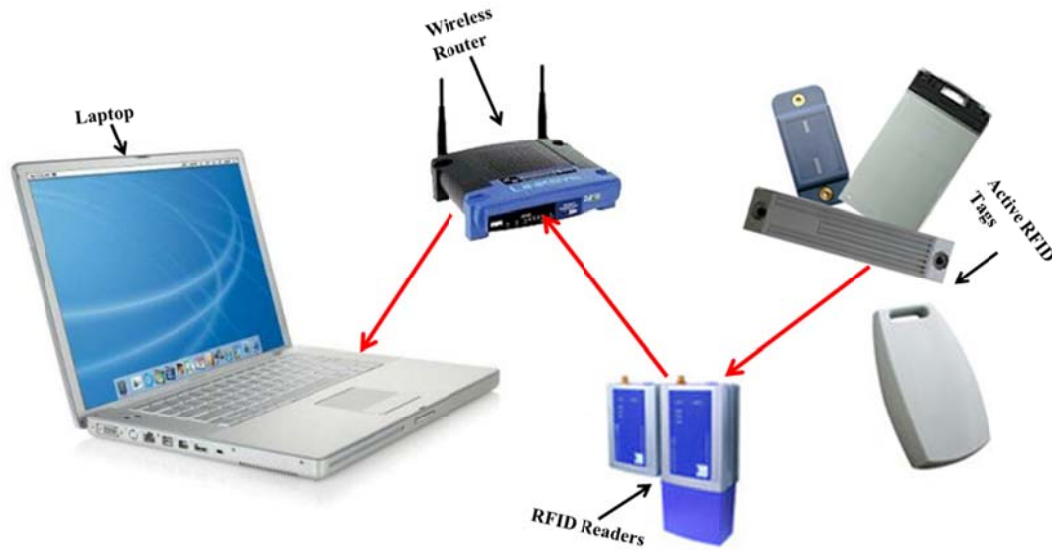


Figure 2.5: Active RFID Tags and Reader Configuration proposed for the study

2.5 RFID Applications

The use of RFID technology in other sectors is also abundantly evident. The use of RFID systems in supply chain management has been advocated in many businesses (Jain, 2014). A study of supply chain of retail businesses using RFID systems found that there are several variables to be considered for its successful implementation (Vlachos, 2014). The use of RFID systems for supply chain management does not automatically indicate better performance, as studies have shown (Leung et al., 2014). However, the use of RFID systems has been demonstrated in supply chain management of several industries including the fashion industry (Buckel and Thiesse, 2014), the aircraft parts supply industry (Ngai et al., 2014), the manufacturing sector (Brewer et al., 1999), the pharmaceutical industry (Yue et al., 2008) and the retail industry (Kärkkäinen, 2003).

The use of RFID was also demonstrated in the healthcare industry to track patients throughout their experience of visiting a hospital (Cao et al., 2014). The use of RFID

systems in the operating rooms of hospitals was also demonstrated to improve all aspect of data collection and storage of patient information (Leu et al., 2014). The use of RFID systems have been demonstrated in the pharmaceutical industry with the intent of preventing counterfeit drugs from entering the market (Schapranow et al., 2012; Wyld, 2008). The use of RFID tags to track the movement of patients in a hospital, from a security perspective has been demonstrated (Chowdhury and Khosla, 2007). RFID system was proposed for a way-finding application for the visually impaired in one study (Sharma et al., 2008).

2.6 Use of RFID in Construction

Academics and researchers have increasingly advocated the use of RFID technology in construction processes, for at least the past decade (Jaseiskis and Ei-Misalami, 2003; Domdouzis et al., 2007; Lu et al., 2011). The use of RFID technology was proposed for automating the processes of material delivery on construction sites (Jaseiskis and Ei-Misalami, 2003). Domdouzis et al.(2007, p. 355) provide examples of RFID usage in the construction industry such as tracking pipe spools and tracking structural steel members and declare that the technology would be ubiquitous in most industries, as evidenced by the statement *“The proliferation of RFID systems suggests that it will be all pervasive, and it is expected that RFID is set to have an important impact on most industrial sectors.”* RFID technology has been proposed as an alternative to the use of barcode technology for tracking objects in the construction industry (Kumar, 2007). One of the advantages of RFID technology over bar code technology is that RFID tags have a built in memory so that it can be used to store and retrieve information about the item that is tagged (Jaseiskis and Ei-Misalami, 2003). The following sections examine the various uses of RFID technology in the construction industry.

2.6.1 RFID Applications in Construction Safety

Studies have shown that RFID tags can be used to prevent collisions between construction worker and heavy equipment (Chae and Yoshida, 2010). Chae and Yoshida (2010) used active RFID tags on workers and placed readers on equipment and at certain fixed places on the construction site to locate workers when they are too close to the equipment. They did not devise a system to alert the worker when a dangerous situation is

detected; however, they suggest that such a warning system would be very useful in practical implementation. Since the research in this PhD proposes to a location based monitoring using RFID, similar to Chae and Yoshida (2010), the superintendent can be enabled to intervene if a dangerous situation is detected, when a worker and certain types of equipment are too close to each other.

RFID technology has been used to demonstrate real-time information gathering for safety applications in the construction industry (Lo and Lin, 2013). Lo and Lin (2013) used RFID tags on construction workers and devised a scheme whereby workers were denied access to the site or an area of the site if their credentials indicated that they should not be allowed entrance. A reader was placed at the entrance of the site/area along with security guards to monitor the situation. This method of tracking has the disadvantage of requiring security guards at the specified choke points. Furthermore, workers may need access to parts of the site where they are not allowed to enter, as the conditions on a construction site are dynamic and the system may need to be constantly updated to allow access to workers to the appropriate areas.

RFID sensors were proposed to study near miss accidents on a construction site by using real-time tracking the movement of personnel, equipment and materials (Wu et al., 2010). Zigbee RFID tags were used in a simulated construction environment to track the movement of workers, equipment and materials. The resulting tag data was examined to determine if a near-miss accident has occurred. This information can be used to prevent such occurrences in the future. In another study Wu et al. (2013) suggest the use of RFID sensor network along with integrated safety management system to prevent accidents from falling objects. They propose a hybrid system of RFID devices along with ultrasound receivers to track the location of workers and materials on the site and make contextual decisions to analyse the safety risks of falling objects based on the location of workers and materials. The proposed system does not provide any warning of an actual object falling but provides a context to determine if conditions on the construction site are such that objects may fall and cause accidents. The proposed system is limited considering that materials such as beams or mechanical equipment have to be hauled into

place at elevated locations and the system does not explicitly identify or prevent situations where an actual object is falling.

Full scale emergency response systems for cities in the event of extreme events are being developed and tested using RFID in combination with other technologies (Peña-Mora et al., 2010). The research proposes a web-based collaboration tool to combine GIS information along with RFID technology that will track equipment and resources within a building and allow first responders to make critical time sensitive decisions regarding the given emergency. Such a system can be useful in an emergency situation but is useful after the construction of a building is already completed. The research in this PhD differs from this study in that safety issues during construction are considered in this thesis.

RFID based real-time tracking information of construction workers in implementing safety on a construction site has also been demonstrated (Lee et al., 2012c). The authors used an active tag based RFID system and included an ‘Assistant Tag’ to locate a tag in space. The ‘Assistant Tag’ is essentially using the location of a known tag to act as a virtual RFID reader to account for signal distortion from the RFID tag. The study used the location information of resources being tracked and represented them in a two-dimensional plan view of a construction drawing. The research proposed in this thesis proposes to take Lee et al.’s method of tracking one step further by representing construction workers in a BIM model, which implicitly includes a virtual 3D environment.

An early warning system using RFID technology was demonstrated for freezing soil conditions in an underground tunnel construction project under the Yangtze river in China (Ding et al., 2013). The proposed system was also used to monitor the location of workers within the tunnel and send them an early warning during an emergency through a portable electronic device so that safety procedures could begin immediately. A two-dimensional drawing was used to display the location of RFID tags in the research. The research proposed in this thesis will explore the use of a BIM model to represent the location of RFID tags in the model.

RFID-enabled mobile smartphones were used in one application to implement safety inspection management systems on a construction site (Lin et al., 2013). Passive RFID tags were attached to safety equipment such as guardrails and safety signs. The location of the tags was centrally managed in a database, which was updated by the safety inspectors. The safety inspectors could also use the information to determine if the equipment was located at the appropriate location within the site. The work attempted in this thesis is different from the standpoint that safety equipment is not tagged or tracked, but instead the location of construction workers will be considered to enable the superintendent to manage safety on the construction site.

In another study, RFID style Zigbee networks were used to remotely monitor the temperature of a construction site to detect unsafe working conditions (Jiang and Hua, 2013). The information gathered remotely was used to monitor the working conditions on the construction site. This research shows how data can be acquired remotely to monitor safety aspects on a construction site and is similar to the research proposed in this thesis in automated data capture for safety management purposes.

The examples presented in this section indicate that the use of RFID technology for safety monitoring purposes is well underway in the construction industry. Further examples of using RFID technology for safety purposes in combination with 3D visualisations is discussed in Section 2.9 of this chapter. The research conducted in this thesis proposes to use RFID technology to track movement of construction workers so that the construction site superintendent is enabled to make safety related decisions.

2.6.2 Other uses of RFID in Construction

RFID tags were used to demonstrate material management of temporary structural members (Oyama and Yabuki, 2007), managing materials in high rise construction using RFID enabled lift cars (Cho et al., 2011) and in the production of precast members in a component factory (Yin et al., 2009). Similarly, other researchers have done substantial work in validating the use of RFID technology for construction applications. They have demonstrated the use of RFID tags to track on-site materials (Song et al., 2007) and automating the supply chain of fabricated pipe spools (Song et al., 2006). In one study

they showed that the time required for tracking materials using RFID technology was reduced by a ratio of 8 to 1, resulting in a productivity increase of 4.2% (Grau et al., 2009). An ‘Information Lifecycle Management’ system for material control was proposed by Lee et al. (2013) using RFID tracking systems. Passive RFID tag systems were used to track the location of materials within a construction site (Montaser and Moselhi, 2014).

Researchers have shown that RFID systems can be used for building maintenance (Ko, 2009) and facility management systems (Ergen et al., 2007). Dziadak et al., (2009; 2008) have demonstrated that RFID technology may be used to track underground utilities to prevent accidental abrasion or rupture during construction. RFID based occupancy detection systems are being proposed to work in unison with HVAC systems to streamline energy usage in buildings (N. Li et al., 2012). Navon (2005) and associates have demonstrated the need for automated project performance control on construction sites and suggested the use of RFID as means to achieve the same (Navon and Goldschmidt, 2003). Wang demonstrated that it was possible to enhance the processes of inspections in construction by means of RFID technology (Wang, 2008). The use of visualisation tools along with RFID technology has been proposed by researchers (Sørensen K, 2009). Pilot studies to show the combination of 4D CAD with RFID technologies have been conducted to demonstrate its use in material tracking (Hu, 2008). Studies have also shown that BIM can be used in combination with RFID technologies for lifecycle maintenance of building equipment (Motamedi, 2009). In one study, Chin et al. (2008) demonstrated that the combination of passive RFID tags with 4D CAD technology saved 17% time in material tracking operations. Passive RFID tags were successfully used to track field mobility of construction workers and status monitoring on construction projects (Costin et al., 2012). Passive RFID tags are also currently being investigated to track the shipping and receiving processes of engineered components to the construction site (Grau et al., 2012).

These examples again indicate that RFID technology has been demonstrated in the construction industry for many purposes. In fact, from a chronological perspective, material tracking appears to be one of the first uses of RFID technology in the construction industry, based on the dates of articles found in the literature. The research

proposed in this thesis does not consider tracking materials or other applications of RFID in construction and the examples presented about material tracking are not direct evidence to advocate for the use of RFID for safety management purposes. However, based on the literature review, an argument can be made for the maturity of RFID and related sensing technologies for automated data collection in the management of construction projects.

2.7 Active RFID Tag Location in Space

Location tracking has been shown as an important aspect in delivering context specific information to users in construction (Behzadan et al., 2008). While this has been successfully developed and utilised in an outdoors environment, location tracking in an indoor environment, while construction is taking place, can be difficult due to signal interference (Behzadan et al., 2008). The interference from RFID tags is primarily due to reflection of the beacon from the tag to the reader. The beacon may get reflected due to the presence of construction objects on site such as structural members, large equipment or walls, etc. Several methods for locating active RFID tags within a construction environment are proposed (Razavi and Haas, 2010). One method for locating RFID tags, called the ‘Centroid’ method, was proposed on an industrial project by Grau and Caldas (2007), which seemed to improve the precision of locating RFID, compared to the ‘Proximity Method’ developed by Song & Haas (Song et al., 2007). The centroid method is based on “... *network connectivity completely and it locates the object by regarding the geometrical centre of surrounding reference points as the centroid which is the predicted position*” (Guo et al., 2008, p. 2). The proximity method of localising tags is based on a field supervisor or material handling equipment be equipped with an RFID reader and GPS tracker to be used as a ‘rover’ to track RFID tag location. The rover would make several reads in the field and the resulting data would be used to calculate the location of the RFID tag. Khoury and Kamat (2009) showed that the precise location of people or objects in an indoor environment requires line of sight based systems and that RFID systems can be inaccurate in locating using various localisation methods. However, Ko (2013) showed that RFID tags could be located with increasing accuracy in a 3D space using multiple localisation methods. Moreover, there is no consensus on what may be considered an acceptable accuracy of location in a construction environment when active RFID tags are used (Lin et al., 2013).

A combination of triangulation and proximity methods may also be used to collect and store passive RFID signal data (Montaser and Moselhi, 2014). Montaser and Moselhi (2014) compared stored data against real time data to estimate the location of the tag, and the method was used for material tracking on a construction site. The results of the study showed that there was an error of less than 2 meters to track materials and less than 3 meters to track workers and 100% accuracy to track materials and workers in specific zones within the construction site. The use of location information is crucial to successfully representing an RFID tag in a spatial zone. The examples presented here show that the problem of location continues to persist in regards to RFID technology. However, examples also show that RFID tag location information can be reasonably ascertained to make decisions related to the object that is tagged.

2.8 Building Information Modelling

Several definitions exist for BIM and the National Building Information Model Standard (NBIMS) defines a building information model as “*A digital representation of physical and functional characteristics of a facility. As such it serves as a shared knowledge resource for information about a facility forming a reliable basis for decisions during its life-cycle from inception onward*” (Facility Information Council, 2007). Eastman et al. (2011) define BIM as “... *a modelling technology and associated set of processes to produce, communicate, and analyse building models*”. The UK BIM initiative concede the many definitions of BIM and describe it as “*BIM is essentially value creating collaboration through the entire life-cycle of an asset, underpinned by the creation, collation and exchange of shared 3D models and intelligent, structured data attached to them*” (BIM Taskgroup, n.d.). For the purpose of this study BIM is referred as ‘BIM technology’ and the inherent data model within BIM is used as a vehicle to incorporate RFID technology.

BIM technology is based on representing building elements using intelligent objects. These objects in a BIM model can be real objects with 3D characteristics such as beams, walls, equipment etc., as well as abstract objects such as spaces, rooms and areas. These objects are often referred to as parametric objects, as they are built with certain inherent

rules, such as requiring a door to be imbedded in a wall and move with the wall (Eastman et al., 2011). BIM technology has been described to improve the overall quality of design, provide better performing buildings, and require fewer change orders during construction (Azhar et al., 2008). BIM has also been described to enable the contractor to optimise the schedule and cost of the project, while also providing for an efficient handover of buildings to owners for operations and maintenance (Azhar et al., 2008). While all the benefits of BIM have been empirically accepted, the determination of a return on investment in BIM has turned out to be much more complicated (Barlish and Sullivan, 2012). The primary concern for calculating a return on investment is how to quantify what did not occur on the site due to the use of BIM and a determination of the severity of the problem that was avoided due to the use of BIM (Giel and Issa, 2013).

There is general consensus in the academic and the AEC industry community that BIM is more than just a software tool. The true impact of BIM is the enabling of comprehensive, digitised and collaborative processes within the AEC industries. The American Institute of Architects (AIA) recognised this seismic shift in the process of designing and constructing facilities and has proposed a new delivery method, namely ‘Integrated Project Delivery’ (IPD) (AIA, n.d.). BIM is the cornerstone of realising the benefits proposed in this new methodology for project delivery. The use of BIM in the US construction industry has been on the rise and is predicted to continue to increase (McGraw Hill Construction, 2012). This section of the thesis provides a brief overview of BIM and its current state in academic research and its current practices in the AEC sector.

2.8.1 Evolution of BIM

In 2012 renowned BIM researcher Charles Eastman described architectural drawings: “*I think architectural drawings are like medieval, archival documents that nobody can understand. They won’t need to understand them 10 years from now*” (McGraw Hill Construction, 2012, p. 45). Two-dimensional (2D) drawings to represent buildings were the norm in the AEC industries until a few years ago. Several 2D drawings, predominantly produced using lines, were required to represent an object in 3D, resulting in inconsistencies within the various views. These drawings were created by hand until the early 1980s and later on using a microcomputer with the advent of CAD programs

(Autodesk, n.d.). Even before the use of the word BIM, researchers have been experimenting with object-based models for buildings (Papamichael et al., 1997). The history of BIM itself is closely tied to several academic researchers including C. Eastman, van Nederveen, F.P Tolman and J. Laiserin (Eastman et al., 2011). The use of BIM in the AEC sector was greatly enabled by the creation of the ‘Industry Foundation Classes’ (IFC) by the ‘International Alliance for Interoperability’ (IAI) in the late 1990s (ifcwiki, n.d.). Developed by the buildingSMART Alliance, the IFC data model is described as “*The data schema comprises information covering the many disciplines that contribute to a building project throughout its lifecycle: from conception, through design, construction and operation to refurbishment or demolition*” (buildingSMART, n.d.a). IFC has become the internationally accepted building product data model standard which can be used to exchange information between BIM authoring programs, among other related software (Eastman et al., 2011). By using an industry standard open file format for data exchange, BIM users are enabled by choosing their preferred software programs with the knowledge that intelligence of the data is not lost during data exchange (Graphisoft, n.d.). As of the writing of this thesis, there are 153 software programs listed on the buildingSMART implementation website, that are capable of implementing IFC for various purposes (buildingSMART, n.d.b).

According to the McGraw Hill Construction (2012) ‘Smart Market Report’, an industry-wide survey of 582 participants (179 architects, 111 engineers, 208 contractors, 36 owners and 48 others) revealed that use of BIM in North America has seen a dramatic increase in adoption from 28% in 2007 to 71% in 2012, as shown in Figure 2.6. The data revealed that of the respondents 74% of contractors, 70% of architects and 67% of engineers were engaged in using BIM as of 2012. The data points to an explosion of software programs as well as widespread use of BIM in the AEC sector. It can be reasonably argued that the dramatic increase in the use of BIM in a few short years is an indication that the benefits of BIM are widely acknowledged in the AEC sector.

Levels of BIM Adoption in North America

Source: McGraw-Hill Construction, 2012

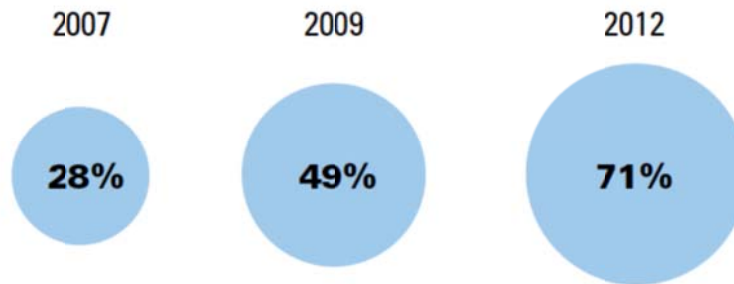


Figure 2.6: Increase in BIM Adoption in North America (Adapted from McGraw Hill Construction, 2012, p. 9)

2.8.2 BIM for Designers

The benefits of using BIM have been well documented in recent years (Azhar, 2011). For the architectural community the adoption of BIM has come with the emergence of new roles, partnerships and collaborations within the industry (Bryde et al., 2013). (McGraw Hill Construction, 2012) found that the architectural community benefits most from the reduction of document errors and omissions in their design, as shown in Figure 2.7. Other benefits of BIM usage for architects include being able to market new business, offer new services, reduced rework and reduced cycle time for specific workflows, according to the smart market report (McGraw Hill Construction, 2012). The report also showed that there is higher level of acceptance regarding these benefits as compared to 2009. Research has shown that architectural firms can benefit from a lean design process by adopting BIM, leading to a competitive advantage (Arayici et al., 2011). Cloud computing technology is being investigated to allow teams of designers to share the model during the design process to improve productivity and collaboration in the design team (Redmond et al., 2012).

Top BIM Benefits for Architects (2009 and 2012)

Source: McGraw-Hill Construction, 2012



Figure 2.7: Benefits of BIM for architects (Adapted from (Adapted from McGraw Hill Construction, 2012, p. 20)

Eastman et al., (2011) describe several aspects of BIM which can be advantageous to the design community. They suggest that BIM use would enable the architects to visualise the design at an early stage, fix low-level errors with changes in the design, generate accurate 2D drawings, allow collaboration between stakeholders at an earlier stage, extract budget estimates during the design stage, check design intent at an early stage and improve the energy efficiency of the building design.

2.8.3 BIM for Contractors

Hartman et al. (2012) have shown that BIM can be used for quantity take off, cost estimation, risk management and other construction management work processes. The Associated General Contractors of America (AGC) is one of the largest organisation of construction professionals in the US and was among the first trade organisations to

promote the use of BIM in the building industry (AGC, 2010). With the advent of BIM, the construction community had to consider the implications of delivering construction projects with new technology-enabled collaborative practices (Becerik-Gerber and Kensek, 2010). This disruptive change was felt in not just the general contractor community but also among specialist contractors (Boktor et al., 2014). Technological changes triggered changes in the industrial practices resulting in the development of several new guidelines for implementing BIM, both within organisations and for the industry as a whole (GSA, 2012; USACE, 2012; AGC, 2010); buildingSMART, 2012; Penn State, 2012). The use of BIM for cost estimation of certain building elements was one of the earliest benefits realised in the construction industry and continues to be further explored (Cheung et al., 2012). The use of BIM for visualisation of various aspects of construction including safety, lean construction, site layout and others has been well documented (Lee et al., 2012a; Sacks et al., 2009; Javier Irizarry, 2012).

Models produced using BIM technology were combined with construction schedules to simulate the sequence of construction and were labelled 4D CAD (Koo and Fischer, 2000; Chau et al., 2004; Chau et al., 2005). These 4D CAD models were used for visualisation, site layout, optimise crane location and life cycle maintenance of buildings (Daniel Hallberg, 2011; Ma et al., 2005; Russell et al., 2009; Tantisevi and Akinci, 2009). RFID technology was combined with the 4D CAD models to optimise construction processes (Chin et al., 2008; Hu, 2008). By attaching the cost information of a project to the 4D CAD models, a new dimension was added and the models were labelled 5D CAD (Larson, n.d.; Muzvimwe, 2011; Vico, n.d.). In this BIM era in the construction industry, 5D models are being explored to rethink the cost estimation processes in BIM-enabled projects (Forgues et al., 2012; Kim et al., 2010). By adding further variables/abstractions to the model such as health & safety, quality control etc., the concept of nD modelling is being proposed (Ding et al., 2012).

The financial benefits of BIM for general contractors and specialist contractors have been documented (Eadie et al., 2013). As shown in Figure 2.8, the most important benefit the construction community cited in the market research report was ‘reduced rework due to BIM use (McGraw Hill Construction, 2012). Other benefits included being able to market

new business, reduced document errors & omissions, maintain repeat business and reduced project durations.

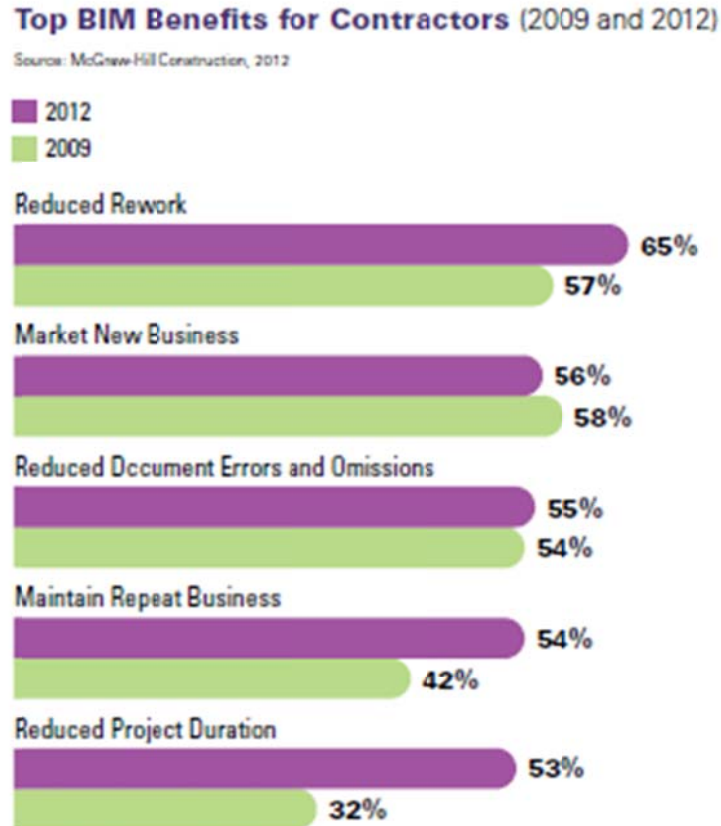


Figure 2.8: Benefits of BIM for Construction Contractors (Adapted from McGraw Hill Construction, 2012, p. 21)

Eastman et al. (2011) describe that the use of BIM would allow the contractor to synchronise design and construction planning, discover design errors and omissions before construction, react quickly to design or site problems, use design model as basis for fabricated components, better implementation of lean construction techniques, synchronise procurement with design and construction. Contractors are using BIM for site logistics, cost estimation, planning, coordination, visualisation and forensic analysis.

2.8.4 BIM and Construction Safety

The use of BIM for safety applications in construction has been promoted in academic research circles (Eadie R, 2013; Stowe et al., 2014; Yalcinkaya and Arditi, 2013). One study concluded that there is empirical evidence that the use of BIM can enable safety management systems in construction organisations (Wan et al., 2013). Researchers have demonstrated that BIM can be used for automated safety checks based on existing standards of safety (Melzner et al., 2013a; Zhang et al., 2012). BIM has been combined with other technologies such as RFID to successfully address issues of ‘Blind Spots’ while using multiple cranes on a construction site (Lee et al., 2012b). Attempts are being made to formally use BIM in the safety planning phase of a construction project (Melzner et al., 2013b; Zhang et al., 2012). BIM has been used in safety trainings to identify hazards in virtual reality environments (Chen et al., 2013). BIM has been used in the design phase of projects to prevent falls during the construction phase (Qi et al., 2013). The use of BIM in identifying tie-off points for safety purposes has been demonstrated by Rajendran and Clarke (2011). The uses of BIM combined with cloud computing technologies have been suggested for maintaining construction health and safety purposes (Bennett and Mahdjoubi, 2013). The use of BIM to assess worker safety in confined spaces is being studied (Arslan, 2014).

These examples of BIM usage in safety applications are an indicator of the effectiveness and increasing popularity of BIM in safety applications. The use of BIM like visualisations has been suggested by researchers for safety applications in the construction industry (H. Li et al., 2012). The studies conducted by Park & Kim (2013) and Cheng & Teizer (2013) are specific examples of using RFID and visualisation programs in safety applications. Considering that the use of BIM is growing at a fast pace in the industry and that it is being used in a variety of applications in the construction industry including safety, it is reasonable to adopt the stance of using BIM to solve safety related issues in construction.

2.9 Role of Visualisation in Construction

Visualisation in the architectural domain has always been an important element to communicate design ideas (Brown, 2003), and more so now with the availability of

complex digital tools (Koutamanis, 2000). Digital visualisation tools are increasingly seen in the construction industry. Researchers like Kamat, Martinez, Behzadan and others have created, improved, demonstrated and validated the use of complex visualisation, simulation tools in the construction industry (Timm and Kamat, 2008). Their research has led to the creation of augmented reality (AR) (Kamat and Martinez, 2001) based visualisation tools that can be used in construction (Kamat and Martinez, 2004). Researchers have created visualisation tools and used the same to simulate the movement of cranes to prevent collision during construction (Behzadan and Kamat, 2009). The role of visualisation tools has especially been on the rise in the area of 4D simulation and virtual construction (Behzadan and Kamat, 2007; Tantisevi and Akinci, 2009). Researchers have been developing, improving and implementing these tools over the past decade (Kang and Miranda, 2006; Kang et al., 2009; Al-Hussein et al., 2006). 4D visualisations have been shown to increase the efficiency of planning and scheduling procedures in the construction industry (Waly and Thabet, 2003). New innovations of 4D visualisations are created to simulate interior construction (Kam and Fischer, 2003). Visualisation tools are also being used in sustainable construction (Chau et al., 2005) lean construction (Ma et al., 2005) and civil engineering education (Li et al., 2009). These are only examples of various research being conducted to enhance the use of visualisations in the construction industry.

2.10 Review of research using RFID and Visualisations for Safety

Researchers have proposed and demonstrated the use of real-time location systems (RTLS) such as RFID in combination with visualisation tools such as BIM, virtual reality (VR) and AR. In this section a critical analysis of these studies is discussed.

Zhang et al. (2013a) proposed using BIM and RFID to enhance the safety practices on a construction site. They propose tagging guardrails, handrails, safety nets and other implements used on construction sites for safety purposes with RFID tags together with using a 4D model in combination with the location of said safety tools to verify if they are in the expected place (Figure 2.9). Zhang et al. proposed an automated safety risk assessment for each space. Zhang et al. also proposed tagging construction workers themselves in an effort to determine their location from a safety perspective. A

combination of Autodesk Revit, Autodesk Navisworks and Revit API was used in the implementation strategy adopted by Zhang et al. Active and passive RFID tags were used in the implementation of their RTLS and the results lead them to conclude that active RFID tags were accurate within 1.5 meters. They used RSSI information to calculate the location of tags within a space.

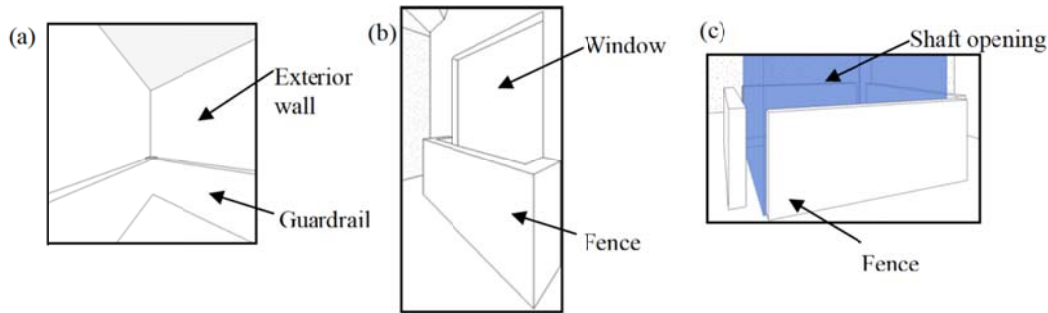


Figure 2.9: Use of RFID and BIM for safety application purposes (Adapted from Zhang et al., 2013a)

The contribution made by Zhang et al. (2013a) is significant in that they are able to determine if the necessary safety gear is present in the location where it is expected to be. However, Zhang et al. do not deliberate a few key issues about the use of RFID and BIM for safety management purpose. As discussed in the literature, the underlying causes of safety incidents on a construction site are numerous and multi-faceted. Zhang et al. (2013a) take a technological approach to using RFID and BIM for safety management purposes and proceed directly to demonstrating the prototype. A theoretical background for how the proposed system fits within the overall activities taking place on a construction site is not addressed. Contextual boundaries for implementing the proposed system were not considered in their study. The solution proposed by Zhang et al. (2013a) does not consider worker behaviour or the supervisor's role in the development of the proposed system. Opinions from industry participants about the efficacy of the proposed system were also not considered by Zhang et al. (2013a). The research in this thesis proposes to consider the use of RTLS for construction worker tracking within the overall context of the activities occurring on the site. The role of the end user (i.e. construction superintendent) in using the proposed prototype to make specific safety related decisions

and how those decisions fit within the overall scheme of site safety is not addressed. Whereas, Zhang et al. (2013a) track the location of safety implements for safety management purposes, this thesis considers the importance of location of construction workers for safety monitoring purposes.

Cheng & Teizer (2013) demonstrated that there are benefits to using visualisations for implementing safety and activity monitoring, using VR technology in a construction context. Cheng & Teizer (2013) focussed on the visualisation aspects of the application and its suitability in specific safety situations, as shown in Figure 2.10. The visualisation includes not only the workers but also the equipment and materials involved in the construction process. The VR visualisation itself is developed from point clouds of site scans and not an existing BIM model. Cheng & Teizer, like Zhang et al. (2013a), take a technological approach to the creation of 3D visualisations using wireless tags for safety purposes. Comprehensive considerations of how the proposed prototype fits within the context of the day-to-day activities on a construction site are not addressed.

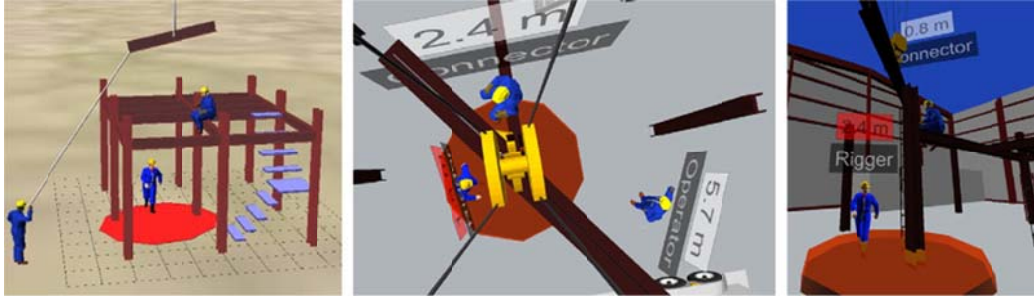


Figure 2.10: Visualisation of a worker's close call, using RFID and VR (Adapted from Cheng and Teizer, 2013, p.9)

Cheng & Teizer (2013) do not establish any theoretical basis for using RTLS and VR for safety purposes but instead declare the importance of knowing the location of construction resources, as evidenced by the statement “*The construction industry has a great interest in systems that provide users with the location of project critical resources (workforce, equipment, materials).*” Cheng & Teizer (2013) then propose, what can largely be considered demonstrator software, applied in three simulated scenarios on the

construction site. Cheng & Teizer (2013) do not address contextual issues about the use of the proposed prototype and its place within the larger picture of overall site safety. They also did not investigate how site supervision and safety personnel view the issue of location monitoring for safety purposes, prior to developing the prototype.

Park and Kim (2013) also propose a visualised system for safety monitoring based on integrating BIM, tracking technologies such as RFID, gaming engines and augmented reality technologies to create an integrated environment (Figure 2.11). They propose that using active RFID technology can identify unsafe conditions on the site and warn workers by sending an electronic warning message when a worker enters the area considered dangerous. Park and Kim (2013) conducted interviews with field personnel about their proposed system and found that there was agreement among them about the usefulness of their research in a construction environment.

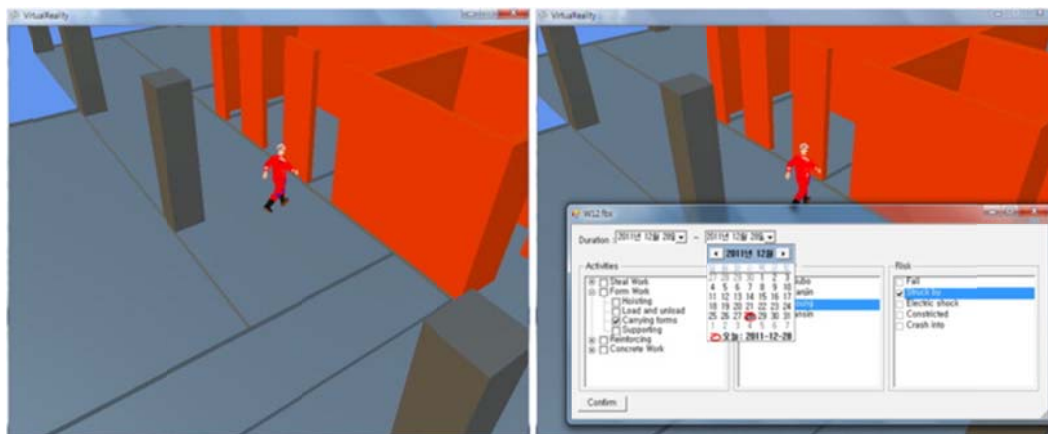


Figure 2.11: Visualisation of risk identification using worker avatar (Adapted from Park and Kim, 2013, p.101)

Park & Kim (2013), like Cheng & Teizer (2013), take a technological approach to their research and provide details of the demonstrator software developed to track the movement of construction workers within the site. The same criticisms from studies conducted by Zhang et al. (2013) and Cheng & Teizer (2013) apply to the work presented by Park & Kim (2013), namely the lack of a theoretical basis to underpin the prototype, not considering safety from a holistic perspective and lack of contextual boundaries for

the implementation of the prototype. However, it is noteworthy that industry participants looked favourably upon the demonstrator software created by Park & Kim for tracking workers for safety purposes.

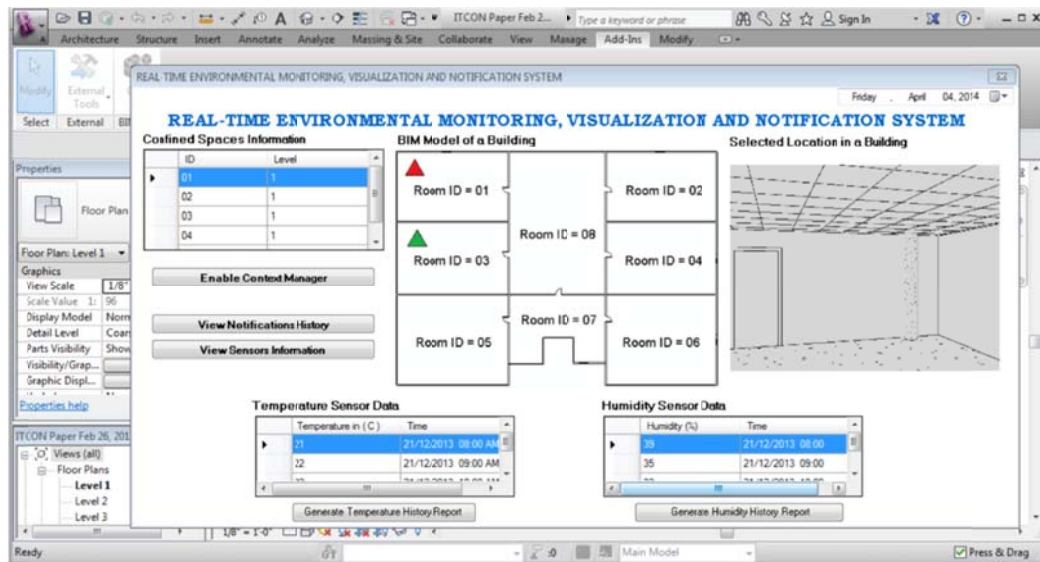


Figure 2.12: Environmental factors monitoring on construction site using RFID and BIM combination (Adapted from Arslan et al., 2014, p.83)

Arslan et al. (2014) used a combination of RFID and BIM to warn workers when the temperature and humidity conditions on the jobsite were deemed unsafe for workers (Figure 2.12). A technology driven approach is taken by Arslan et al. (2014) in the creation of safety warning demonstrator software using RFID and BIM to monitor unsafe temperature conditions on a construction site and as such the drawbacks of taking that approach have been highlighted earlier in this section. The study found that there was agreement among industry professionals who were exposed to the demonstrator software, that the proposed system of visualising site conditions for health and safety purposes in real-time is effective. The authors conclude that the combination can be used to monitor the environmental conditions on the site and advocate its use for safety from an overall perspective, as evidenced by the statement “*However, these systems primarily focus on building energy monitoring and management. There is a need to explore further the integration of BIM with sensors for health and safety management*”. The proposed

research in this thesis is similar to Arslan et al. (2014) in that it proposes a technological solution to address health and safety issues on a construction site. However, the research proposed differs in significant ways to the Arslan et al. (2014) in that: (a) Arslan et al. (2014) focus on the demonstrator software created for the purpose of safety monitoring without a focusing on establishing a theoretical underpinning for developing the demonstrator software. (b) Arslan et al. (2014) propose to monitor the environmental conditions on the construction site, as it relates to safe working conditions, do not consider the use of construction worker location on site to make safety related decisions.

2.11 Rationale for Combining RFID and BIM for Safety Monitoring

An overview of the core issues related to the scope of this thesis has been presented in this chapter. The following sections explicitly justify the significance of this thesis, gaps in the literature that are addressed in this thesis and justification for choosing the technology based approach to address a construction site safety issue.

2.11.1 Site Safety in the Construction Industry

The importance of safety in the construction cannot be emphasised enough considering that there are annually over one thousand people killed in the US construction industry alone (Bureau of Labor Statistics, n.d). Annually, worldwide it has been estimated that the number of fatalities in construction is around sixty thousand per year, almost equal to the number of fatalities in state sponsored armed conflicts around the world (NEBOSH, n.d). However, as described in the literature review earlier, the causes for safety incidents are numerous, in part due to the complex nature of work carried out in the construction industry (Chae and Yoshida, 2010). A majority of accidents occur due to unsafe acts by workers rather than unsafe conditions on the site and it is much easier to address unsafe conditions on the construction site rather than unsafe acts by construction workers (Heinrich et al., 1980). Proposals that attempt to minimise safety risks have to consider the issue within the larger context of the all activities occurring on a construction project. Literature has shown that the superintendent plays a crucial role in ensuring the health and safety on a construction site (Kines et al., 2010). Furthermore, direct supervision of workers has been shown to reduce accidents and has been suggested as a viable strategy to minimise accidents (Bureau of Labor Statistics, n.d.). In this thesis, an examination of

how the construction site superintendent may be enabled to make safety decisions in real-time by using technology-based tools will be explored.

2.11.2 Location Monitoring and Safety

The construction site is often a chaotic environment in which hazardous working conditions not only exist but also are constantly shifting within the site (Hinze et al., 1998). Literature has shown that accidents occur due to unsafe conditions as well as unsafe acts by workers and that it is more difficult to control unsafe acts by workers on the construction site, as compared to rectifying unsafe conditions. Construction workers are often moving around within the construction site to either perform work or to access the site or move materials. Literature has also shown that accidents are most likely to occur when construction workers are moving around the site to access materials or while entering or leaving the site (HSE, 2003a). In fact some studies found that workers moving about on the site was the number one reason for accidents on construction sites (HSE, 2003a). Researchers have been arguing for the use of location-based systems for site safety purposes (Cheng and Teizer, 2013). However, it must be acknowledged that the role of location monitoring of construction workers for safety purposes is but one aspect of implementing a safety plan on the construction site. The issues identified in the CDM guidelines such as designing for safety, engagement of workers in developing a safety plan, training workers for performing construction tasks and others are outside the scope of this thesis; however, their contribution to the overall success of safety outcomes on a construction site remains crucial, based on findings from previous research (Agrilla et al., 1999).

A few studies have addressed the issue of representing worker locations within a construction site, in a virtual environment for safety purposes (Arslan et al., 2014; Cheng and Teizer, 2013; Park and Kim, 2013; C. Zhang et al., 2013). However, these studies take a predominantly technological approach to the issue and were detailed descriptions of demonstrator software development (often referred to as the prototype) and corresponding implementation scenarios. These studies did not place emphasis on how the proposed prototype fits within the backdrop of typical activities taking place on a construction site or how it fits in with the overall safety strategy within a construction

site. Important issues such as contextual implementation of the suggested prototype within a construction site were not considered. The end-users role in using the prototype (i.e. the site superintendent or safety officer) and how the location monitoring system for safety fits within their overall duties are not addressed. The research in thesis attempts to consider the issue of location monitoring within the context of the activities taking place on the construction site, the problem as seen by construction professionals and contextual scenarios to enable the site superintendent to make safety related decisions in real time. In other words, a theoretical basis for implementing location monitoring of construction workers, as it pertains to safety related decisions would be explored in this thesis.

2.11.3 BIM for Location Monitoring Visualisation

The popularity and interest in BIM within the construction industry is increasing and may serve as a backbone in construction projects for the foreseeable future in the AEC sector (McGraw Hill Construction, 2012). The innovative uses of BIM in various construction applications demonstrates that it has been accepted by construction professionals for use in numerous ways to assist in the construction process (Bryde et al., 2013). It has not only grown in popularity, but also is advocated and accepted as the ‘go-to tool’ for managing a facility from inception to construction and maintenance (buildingSMART, n.d.; McGraw Hill Construction, 2012). It is implicit that BIM provides a virtual 3D model that can be used to represent not only intelligent building objects but also other external real world objects such as objects attached to an RFID tag (Zhang et al., 2013a).

There are other visualisation technologies available in the construction industry such as VR & AR. These may be acceptable alternatives to BIM to represent the location of workers, but the popularity of BIM in the construction industry suggests that superintendents and safety officers are likely to be familiar with BIM. In fact, studies that have used BIM for safety applications in the construction industry have also been found, as shown in Table 2.1 (Lee et al., 2012a; Rajendran and Clarke, 2011; Zhang et al., 2012). Since construction safety is the focus of this research, it is appropriate to choose a tool that is familiar to construction site superintendents and safety managers. Increasingly BIM models are being passed from the design team to the construction team (Shafiq et al., 2013). By extending the use of BIM for safety purposes, the construction teams would

not need to develop new visualisations for location monitoring systems. This research proposes extending the use of BIM to enhance safety on a construction site and is not an argument for or against other visualisation technologies for the same purpose.

2.11.4 RFID for Location Monitoring

Sensing technologies are abundantly being used in day-to-day activities and the use of RFID has been demonstrated in the construction industry for numerous applications. While studies specifically about the increasing popularity of RFID have not been found, based on the examples discussed from the literature, it can be reasonably assumed that RFID technology can be fully integrated into construction processes. RFID systems have also been used in safety applications and studies to combine RFID & BIM technologies (or similar visualisation methods) to monitor site safety have also been found (Arslan et al., 2014; Cheng and Teizer, 2013; Park and Kim, 2013; Zhang et al., 2013a), as shown in Table 2.1. A critical analysis of their research was presented in Section 2.9 of this chapter.

The use of RFID technology for construction safety applications has been demonstrated by previous studies, as shown in Table 2.1. Since this thesis considers the use of construction worker location for safety purposes, it stands to reason that a familiar tool be used in facilitating the location of workers on site. It must also be noted that no wireless tracking technology, other than vision based technologies that have their own limitations, has emerged above all others as fool proof or more advanced in accurately sensing construction resources in space (Brilakis et al., 2011).

Study	Synopsis	Implication
Zhang et al., 2012	BIM was used for safety planning purposes	BIM is already being used in safety application on construction sites.
Lee et al., 2012	BIM was used to prevent crane accidents by eliminating blind spots	
Rajendran & Clarke 2011	BIM was used to identify tie-off points.	
Teizer, et al., 2010	RFID technology was used to alert workers when they entered hazardous areas	RFID is already being used in safety applications on construction sites.
Riaz et al., 2006	RFID Technology was suggested as a possibility to prevent vehicle collisions with workers	
Lee, et al., 2012	RFID based real time tracking of workers for safety management	
Cheng and Teizer, 2013	RFID and VR Systems were used for safety visualisation applications	The use of RFID and BIM (or similar visualisation tools) for safety management issues is being researched
Park and Kim, 2013	RFID and BIM are proposed and tested for safety applications	
Arslan et al., 2014	RFID & BIM used to monitor environmental conditions for worker safety	
Zhang et al., 2013a	The use of RFID and BIM for safety purposes by tagging safety equipment	

Table 2.1: Related studies using RFID, BIM and other visualisation technologies for site safety purposes

2.12 Summary

This chapter presented an overview of issues relating to construction safety, role of construction supervision in safety, RFID technology and its uses in construction, specifically use of RFID in construction safety, the use of BIM, the evolution of BIM and its use in the AEC sector. The use of BIM in construction safety applications was discussed. The evolving landscape of digital visualisations in the construction industry was presented. A rationale of combining RFID and BIM for monitoring safety of construction workers was discussed. The next chapter discusses the philosophical and methodological choices available to conduct this research together with the appropriate justifications for making such choices.

CHAPTER 3

RESEARCH DESIGN & METHODOLOGY

3.1 Introduction

Chapter 2 presented a critical review of the literature on issues relevant to the aim of combining RFID and BIM technologies for safety monitoring on a construction site. The review provided a rationale underpinning this research based on literature concerning health & safety on construction sites, supervision on construction sites, the various uses of technologies such as RFID, BIM and digital visualisations in the construction industry. This chapter is devoted to a discussion of the design and methodological constructs chosen for this research. The justification, relevance and adequateness of the research design and methods are presented in this chapter. The philosophical underpinnings of this research and the associated data collection and analysis methods employed are presented.

3.2 Research Methodology

The Oxford dictionary (n.d.) defines the term ‘Research’ as “*The systematic investigation into and study of materials and sources in order to establish facts and reach new conclusions*”. The logical approach to the principles and procedures of conducting scientific research is the ‘Research Methodology’ (Fellows and Liu, 2009). A substantial body of knowledge exists about the principles of research, describing the philosophical aspects, approaches, designs, strategies, methods, etc. Bryman (2012), Creswell (2007), Kagioglou et al. (2000) and Saunders et al. (2009) all presented various models for conducting social research. A model for conducting research in this context is the holistic manner of conducting a research process presented by each of these authors.

Bryman (2012) presents that the relationship between theory and research guides the researcher in adopting the appropriate epistemological and ontological stance. This choice then leads to the adoption of an appropriate research strategy, namely ‘quantitative’, ‘qualitative’ and ‘mixed method’. Creswell (2013) defines the research design or the plan to conduct research involves the intersection of philosophies, strategies of inquiry and specific methods. Creswell (2013), like Bryman (2012), presents a framework for research design identifying ‘quantitative’, ‘qualitative’ and ‘mixed methods’ as the predominant strategies.

Creswell (2013) points out that the ‘quantitative and ‘qualitative’ strategies, instead of being the polar opposite of one another are in fact part of a continuum with ‘mixed methods’ occupying the middle of that continuum. Kagioglou et al. (2000) present a nested approach to research whereby the choice of technique / tool employed is reached by a process of narrowing down from the philosophical stance adopted and then the selecting an appropriate paradigm.

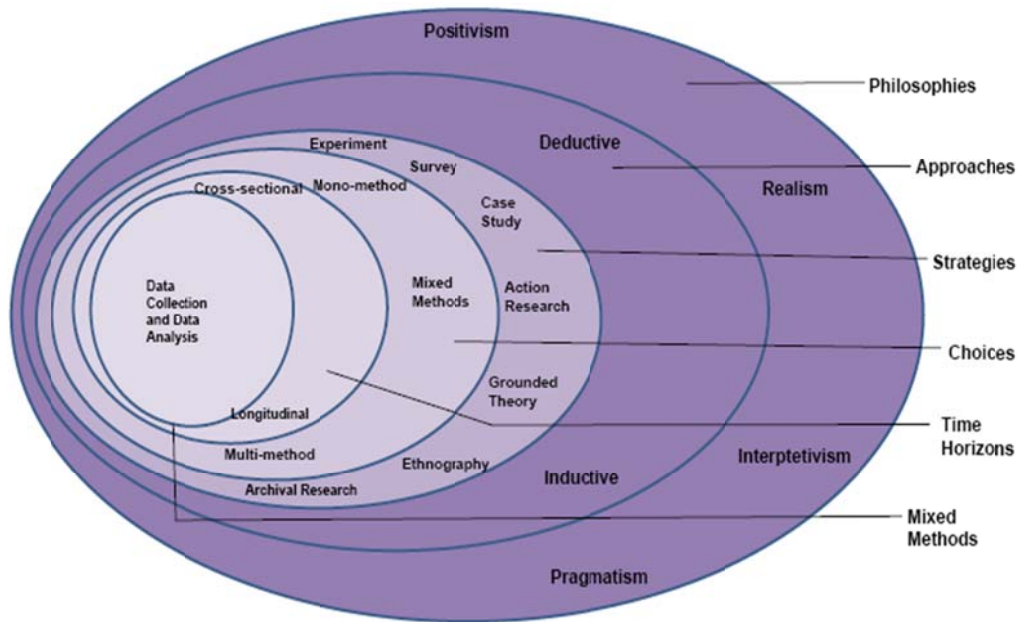


Figure 3.1: *The Saunders Research Onion* (Saunders et al., 2009, p. 138).

The Saunders et al. (2009) model of the research onion shown in figure 3.1 is utilised as the basis for developing and describing the research process for this project. It must be acknowledged that any of the models identified or several similar others could have been chosen to conduct this research. The Saunders et al. (2009) model was chosen as it was specifically written for business students. Since this research is about the business of construction, it is therefore an appropriate model to adopt to conduct this research. Each layer of the Saunders onion was considered in choosing the approach for this research. The Saunders et al. (2009) model is similar to the model presented by Kagioglou et al, (2000) in that the choice made at each layer of the onion correlates with the choices

available in the next layer of the research onion. Kagioglou et al, (2000) present the nested approach wherein the ‘Research Philosophy’, ‘Research Approach’ and ‘Research Techniques’ are selected sequentially, like peeling the layers of the Saunder’s onion.

3.3 Research Philosophy

In the outermost layer of the research onion, Saunders et al. (2009) present the philosophy of conducting research and describe the various points of view of choosing a particular philosophy. ‘Research Philosophy’ refers to the development and nature of knowledge (Creswell, 2007). The choice of research philosophy used also dictates the assumptions with which the world at large is viewed by the researcher (Collins, 2010). The assumptions associated with the research philosophy form the underpinnings of the research strategy employed (Creswell, 2007). A positivist approach is often quantitative and is commonly used for pure scientific research. The positivist approach is that an objective reality exists external to the actors involved and that new knowledge is added to existing knowledge in a sequential and cumulative manner by eliminating false hypotheses (Näslund, 2002). A phenomenological approach is generally classified as a qualitative style of research and is often employed for conducting social research, which generally tends to be based on observations (Neuman, 2011). The Saunders et al. (2009) model shown in figure 3.1 identifies the philosophical stance for positivism and phenomenology as a continuum of the various choices available to social researchers. Denzin & Lincoln (2011) argue that qualitative research is fast replacing quantitative research especially in the field of social research. For example, the implementation of site safety depends on several aspects including issues such as ‘safety bias’, safety training, management buy-in, superintendents’ experience, workers’ experience etc. These factors vary from company to company, jobsite to jobsite and most importantly from person to person. A phenomenological philosophy implicitly admits that superintendents’ perspective regarding safety is shaped by their experiences and beliefs rather than explicit, objective reality outside of these perceptions (Fellows and Liu, 2009). By using a phenomenological approach this research aims to understand superintendents’ perspective of site safety, their approach to various situations on site and their perspective on automating certain aspects of site safety practices. Hence, for the purpose of this research, a phenomenological philosophy is adopted. Ballantyne (2008) describes ontology and

epistemology as two branches of the philosophical choices. In the context of social research, Bryman (2012) describes ‘Ontology’ as the consideration of reality with regards to social entities and ‘Epistemology’ as the consideration of acceptability of knowledge.

3.3.1 Ontology

Ontology refers to the nature of reality and speaks to the assumptions of the researcher about the world at large (Corbin and Strauss, 2008). The ontological stance adopted address the assumptions through which the researcher perceives the question of how the world operates (Saunders et al., 2009). Objectivism represents that social entities exist external to the social actors concerned with their existence (Bryman, 2012; Creswell, 2007). Subjectivism, on the other hand, holds that social phenomena are created by the perceptions and corresponding actions of those social actors concerned with their existence (Saunders et al., 2009; Barrett and Barrett, 2003). Objectivism can be considered a positivist’s approach to ontology whereas subjectivism can be considered a phenomenologist’s approach. Construction professionals’ view of safety is shaped by their experiences and their perceptions of its importance in the construction industry. By adopting subjectivist ontology this research aims to understand how superintendents implement site safety, their perceived problems with implementing site safety and their ideas for solutions to those problems. Therefore subjectivist ontology is chosen for this research.

3.3.2 Epistemology

Epistemology is the theory and nature of knowledge and what is considered acceptable knowledge in a particular field of study (Bryman, 2012). Positivism in the context of social research would indicate the researcher would make generalisations based on observable social reality (Bryman, 2012). Realism, much on the lines of positivism, holds that reality exists independent of the human mind (Bryman, 2012). Interpretivism stems from the phenomenological perspective that requires researchers to take a different approach to humans unlike studying objects like phones or cars (Bryman, 2012). The researcher must take an empathetic stance to understanding the subjects and try to understand the world from their point of view (Saunders et al., 2009). The implementation of safety practices on a construction site is a human activity and its

effectiveness is often based on people's perspective of issues such as 'optimism bias' (Caponecchia and Sheils, 2011). Also, considering the phenomenological approach chosen earlier, from an epistemological standpoint, this research takes an interpretivist approach.

3.3.3 Summary of Research Philosophy

In summary, 'research philosophy' represents the nature of developing new knowledge; whereas, ontology addresses the question of "what is there to be known?" and epistemology address the question "how do we know what we know?" Bryman (2012) suggests that the ontological assumptions of a study cannot be divorced from the conduct of social research as these assumptions would guide the framing of the research question and the conduct of the research. Saunders et al. (2009) suggest that the researcher's view regarding what may be considered as acceptable knowledge dictates the lens through which the researcher chooses to interpret the meanings of the study. Therefore a consistent stance must be adopted with respect to the choices made with regards to the 'philosophy', 'ontology' and 'epistemology' of a research undertaking. In this research, a 'phenomenological' philosophy, 'subjectivist' ontology and an 'interpretivist' epistemology are adopted.

3.4 Research Approach

The next layer of the Saunders et al. (2009) research onion considers the 'Research Approach' addressing the theme of 'Theory' development. *'Theory is about the connection between phenomenon, a story about why events, structure and thoughts occur'* (Sutton and Staw, 1995, p. 378). The use of theory therefore is inevitable in the research process. However, answering the question of whether theory is the first step of the research process or is the result of actions taken in the research process presents two ways that are opposite in their underlying assumptions. This choice is referred to as the 'Research Approach' in the Saunders et al. model (2009). Two broad methods of reasoning are prevalent in research, namely the 'inductive approach' and the 'deductive approach'.

3.4.1 Deductive Approach

A deductive approach involves the development of a theory that is thoroughly tested. It is the common approach for the objectivist ontology and is widely used in natural sciences where laws are the basis of explanation of phenomenon (Collis & Hussey, 2003). The initial development of the theory often leads to the development of a hypothesis which is then subject to rigorous testing and may lead to the validation of the theory or may lead to further adjustment of the theory and the process is repeated. This approach is also referred to as going from the ‘general’ to the ‘specific’ and also as the ‘top-down’ approach.

3.4.2 Inductive Approach

An inductive approach involves observations leading to the development of theory. In the inductive approach, observations made are generally studied within the context of the phenomenon. The inductive approach is commonly used in the subjectivist ontology and is referred to as ‘bottom-up’ approach and going from the ‘specific’ to the general. It is also acknowledged that it is not necessary to make generalisations when an inductive approach is chosen and furthermore, it may not be possible to make generalisations as the theory is based on a set of circumstances and often with social actors. Therefore a deductive approach is better suited for a positivist paradigm whereas the inductive approach is better suited for the interpretivist paradigm (Collins, 2010).

Site safety issues have to be studied within the context of the workers, the site superintendent, the conditions on the jobsite etc. Thus an inductive approach is chosen for this research. Themes and categories will be developed from the data collected in this research, which in turn lead to the creation of a framework for monitoring construction workers using RFID and BIM.

3.5 Research Strategy

The Saunders et al. (2009) model refers to ‘research strategy’ as the tools employed to conduct the research. Some of the common research strategies employed include ‘experiment’, ‘survey’, ‘action research’, ‘grounded theory’, ‘ethnography’, ‘archival research’ and ‘case study’ (Saunders et al., 2009). Each strategy again has within it certain inherent rules that are acknowledged to be standard procedures for that particular

strategy. A more detailed account of each of these strategies is presented in greater detail in subsequent sections of this chapter.

3.5.1 Experiment

An ‘experiment’ is often considered by many as the most rigorous approach to research and seeks to eliminate alternate explanations of findings (Trochim, 2006). This is accomplished by assigning an experimental group that is subjected to a particular treatment or by random assignment of the treatment to a control group and a non-control group (Creswell, 2007). The experimental method of research is often associated with a quantitative study and is often employed in a positivist context of research. Chapin (1917, p. 133) says ‘*The experimental method has contributed in large measure to the striking achievements of modern science. This method allows us to analyse our relations of cause and affect more rapidly and clearly than by any other method*’.

3.5.2 Survey

A ‘survey’ is a technique to generalise findings based on data derived from sampling populations. As such a ‘survey’ approach involves the self-completion of a questionnaire or a structured interview, used to collect data that can detect patterns of relationships between variables (Bryman, 2012). Survey research is a commonly used technique in applied social research involving feedback for a questionnaire or a detailed interview (Trochim, 2006). The data can be derived from a self-completion questionnaire that may be administered by supervision or by post or more recently through the use of email or the Internet. Alternatively, survey data may be obtained by a face-to-face or telephone interview. A representative sample that reflects the population accurately is essential to the validity of the results of the survey technique (Bryman, 2012).

3.5.3 Action Research

The term ‘action research’ involves the researcher and a client collaborating to diagnose and solve a problem (Bryman, 2012). Action research became popular in the 1980s & 1990s and is taken up by people who want to improve their understanding of practice within an organisation in order to improve their dealings with others in a social context (McNiff & Whitehead, 2001). This form of research is common in the areas such as

business management and involves people within the organisation in the diagnosis of problems and coming up with appropriate solutions rather than imposing solutions to pre-defined problems (Bryman, 2012).

3.5.4 Grounded Theory

The term ‘Grounded Theory’ was introduced by Glaser & Strauss in 1967 (Glaser and Strauss, 2009). Grounded theory involves the development of theory and using qualitative data to refine the theory (Bryman, 2012). The development of theory using data is a central theme in grounded theory and as such data gathering and data analysis occur simultaneously (Oktay, 2012). Data is continuously gathered and analysed to refine the theory until ‘saturation’ occurs wherein no new themes are emerging from the data (Oktay, 2012).

3.5.5 Ethnographic Research

In ‘Ethnographic Research’, the researcher is involved for an extended period in the social life of those being studied and draws conclusions from the observation of participants (Bryman, 2012). Ethnographic research is qualitative in nature and tends to use a collection of approaches such as observation, informal interviews and informal correspondence such as e-mail and letters (Szewczak and Snodgrass, 2002).

3.5.6 Archival Research

‘Archival Research’ implies that the researcher uses data from existing archival records, which the researcher had no part in collecting (White, 2012). Bryman (2012) describes this form of research as ‘unobtrusive’ in nature as the researcher is not involved in observing the interactions or events being studied. The use of government-collected data such as census data is an example of archival research.

3.5.7 Case Study

Yin (2009, p. 18) describes the case study method as ‘...an empirical inquiry that investigates a contemporary phenomenon in depth and within its real-life context, especially when the boundaries between phenomenon and context are not clearly evident’. A case itself can be defined as a single person, subject, group or organisation

(Corbin and Strauss, 2008). Case study research may involve the investigation of a single case or multiple cases and can be categorised as ‘descriptive’, ‘explanatory’ or ‘exploratory’ in nature. A descriptive case study is used to describe a phenomenon or a processes whereas an explanatory case study is usually theory driven and may be used to develop hypothesis in a large research project (Fellows and Liu, 2009). An exploratory case study is typically used to test hypothesis to come up with logical conclusions (Yin, 2009).

3.5.8 Research Strategy Summary

The research aim, the research approach, the philosophical underpinnings, the amount of time available etc., typically dictate the choice of strategies available to research a question (Saunders et al., 2009). The strategies for this research must validate that construction site safety supervision can be improved by creating a framework for monitoring the movement of workers on a jobsite, using RFID and BIM technologies. Every construction jobsite is unique due its geography, local culture, size, budget, schedule, location, type of project, etc. Furthermore, there are hundreds of construction sites that exist in any given geographical area, each with its own variations. Therefore, it is also not feasible to conduct an industry wide research of an exploratory innovation.

Multiple research strategies will be adopted in the conduct of this research. Qualitative survey strategy is proposed in the creation of a conceptual framework to monitor site safety of construction workers using RFID and BIM. Lapan et al. (2011) identify the survey strategy may be employed in both qualitative and quantitative contexts. A further explanation of the differences between qualitative and quantitative approaches is presented in section 3.6 of this chapter. As part of the qualitative survey strategy, semi-structured interviews with construction site superintendents will be conducted. Saunders et al. (2009) suggest the use of qualitative interviews as an acceptable strategy for an exploratory study. The methods proposed as part of this strategy are further elaborated in section 3.8 of this chapter.

The conceptual framework will then be validated using a quantitative survey strategy. Saunders et al. (2009) and Longhofer (2012) identify the survey as a valid instrument in a

quantitative context. The methods employed as part of this strategy are further elaborated in section 3.8 of this chapter.

In the final step, a software prototype will be developed to combine RFID and BIM to monitor safety of construction workers. In an effort to demonstrate the proof-of-concept software prototype, scenario simulations of a construction site will be conducted in a virtual environment. The experiment will be conducted to simulate the use of the framework for combining RFID & BIM for monitoring the movement of workers, using the software prototype. The methods employed as part of this strategy are further elaborated in section 3.8 of this chapter.

3.6 Research Choice

‘Qualitative’, ‘Quantitative’ and ‘Mixed-Method’ are presented by Saunders et al. (2009) as the available options for the choice of research. The choice adopted must consider the nature of the research being conducted and the data that will be collected in the process. Frequently a ‘mixed-method’ research strategy may be undertaken which combines qualitative and quantitative strategies in a single study. Creswell (2013) presents that mixing qualitative and quantitative methods results in a process of ‘triangulation’ to seek convergence of the results. Denzin and Lincoln (2011) describe the concept of ‘methodological triangulation’ as the combination of multiple methods to study a phenomenon. Bryman (2012) presents that triangulation allows the use of quantitative research to corroborate the findings of qualitative research or vice versa.

3.6.1 Quantitative Study

Creswell (2007, p. 2) defines a quantitative study ‘... *is an inquiry into a social or human problem, based on testing a theory composed of variables, measured with numbers, and analysed with statistical procedures, in order to determine whether predictive generalisations of the theory hold true*’. Quantitative research has its philosophical roots in the positivist school of thought (Newman and Benz, 1998). While quantitative research tends to use numbers to describe phenomenon, Gorard (2003) argues that use of numbers is an essential aspect of any research but cautions against using numbers at face value. Newman & Benz (1998) argue that historically speaking quantitative methods were pre-

dominantly used in social research and only recently qualitative methods are increasingly considered in social research. The quantitative approach is somewhat central to the positivist school of thought and continues to play an important role in the study of physical sciences such as physics, chemistry and mathematics.

3.6.2 Qualitative Study

Fellows & Liu (2009, p. 8) describe qualitative research as ‘...*an exploration of the subject is undertaken without prior formulations – the object is to gain understanding and collect information and data such that theories will emerge*’. Qualitative studies depend on the researcher being an integral part of data collection, in a real world setting and interpreting the results in an enumerative manner rather in numerical terms (Saini and Shlonsky, 2012). Qualitative research tends to focus on a single subject or unit or a case is the focus and is studied in phenomenological perspective (Newman and Benz, 1998). Bryman (2012) argues that several similarities exist between qualitative and quantitative studies.

In the context of social research, Bryman (2012, p. 393) describes the differences between qualitative and quantitative research as presented in table 3.1. Bryman (2012) suggests that the differences between the two as:

Quantitative Research vs. Qualitative Research	
<i>Qualitative Research</i>	<i>Quantitative Research</i>
<i>Words</i>	<i>Numbers</i>
<i>Point of view of participant</i>	<i>Point of view of researcher</i>
<i>Researcher is close</i>	<i>Researcher is distant</i>
<i>Theory Emergent</i>	<i>Theory Tested</i>
<i>Process</i>	<i>Static</i>
<i>Unstructured</i>	<i>Structured</i>
<i>Contextual Understanding</i>	<i>Generalisation</i>
<i>Rich Deep Data</i>	<i>Hard Reliable Data</i>
<i>Micro</i>	<i>Macro</i>
<i>Meaning</i>	<i>Behaviour</i>
<i>Natural Setting</i>	<i>Artificial Setting</i>

Table 3.1: Differences between Qualitative Research & Quantitative Research. Adapted from Bryman (2012, p. 393).

- *Numbers vs. Words*: Quantitative researchers tend to apply measurement procedures to understand social meanings whereas qualitative researchers tend to analyse words for the same purpose.
- *Point of view of researcher vs. Point of view of participants*: Quantitative researchers begin with a set of concerns that guide the structure of the investigation whereas the qualitative researcher is more concerned with the perspective of those being studied.
- *Researcher is distant vs. Researcher is close*: It is not unusual for the quantitative researcher to have little or no contact with the subject being studied whereas the

qualitative researcher seeks close contact with the subjects being studied so as to understand issues through their perspective.

- *Theory and concepts tested in research vs. Theory and concepts emergent from data:* Quantitative researchers tend to test a theory or concept whereas the qualitative researcher develops theory from the data.
- *Static vs. Process:* Quantitative research tends to be presented as a static image of social reality with emphasis on relationships and variables that are often reported in a mechanistic manner. Qualitative research, on the other hand, is almost always unstructured to understand the meanings and concepts emerging from the data.
- *Structured vs. Unstructured:* Quantitative researchers approach their work in a structured and methodical manner to test their theories and concepts whereas qualitative research is almost always unstructured as the researchers seek to understand meanings of actors' to develop theory and concepts.
- *Generalisation vs. Contextual understanding:* Quantitative researchers tend to make generalisations from the data, relevant to the population being studied whereas the qualitative researcher tries to understand behaviour, values and beliefs of the subjects being studied.
- *Hard, reliable data vs. Rich, deep data:* Quantitative data is often claimed as being hard, robust and unambiguous whereas qualitative researchers present their data as being richer in meaning due to their intimate involvement in collecting the data.
- *Macro vs. Micro:* Quantitative researchers are considered to uncover large-scale trends of a population while qualitative researchers are seen as uncovering smaller aspects of social reality.
- *Behaviour vs. Meaning:* Quantitative researchers are depicted as being concerned about the behaviour of a population while the qualitative researcher is concerned with the meaning of action.
- *Artificial settings vs. Natural settings:* Quantitative research tends to be conducted in an artificial setting whereas qualitative research is typically conducted in the natural setting of the subjects studied.

3.6.3 Mixed-Method Study

A mixed-method study involves combining both qualitative and quantitative approaches into a single study (Saini and Shlonsky, 2012). An example of this is when qualitative data is collected and analysed by conducting interviews and quantitative data is collected and analysed by conducting a survey. Tashakkori & Teddlie (2003, p. 195) argue that ‘*The major strength of mixed methods design is that they allow for research to develop as comprehensively and completely as possible*’. Creswell (2013) argues that ‘triangulation’ as the key reason to combine qualitative and quantitative methods but proceeds to point out other reasons in support of mixed method research design, as shown in table 3.2. Creswell (2013) argues that the methods are complementary and allow for different facets of the phenomenon to emerge, and uses the analogy of peeling the layers of an onion. The methods can be used sequentially to help the second method inform the first method. The notion of ‘initiation’ wherein contradictory evidence might present a fresh perspective and the notion of ‘expansion’ wherein the scope and breadth of the study may be broadened are also argued by Creswell (2013).

Reasons for Conducting Mixed Method Research
<ul style="list-style-type: none"> ➤ <i>Triangulation in the classic sense of seeking convergence of results</i> ➤ <i>Complimentary, in that overlapping and different facets of a phenomenon may emerge (e.g., peeling the layers of an onion)</i> ➤ <i>Developmentally, wherein the first method is used to sequentially to help inform the second method</i> ➤ <i>Initiation, wherein contradictions and fresh perspectives emerge</i> ➤ <i>Expansion, wherein the mixed methods add scope and breadth to a study</i>

Table 3.2: Mixed method research design. Adapted from Creswell (2013, p. 175).

Saunders et al. (2009) further distinguish that in mixed-method research qualitative and quantitative strategies are not combined in the data collection and data analysis stages thus setting apart from ‘mixed-model’ research where qualitative and quantitative data are combined in the data collection and data analysis stages. Saunders et al. (2009) draw a

further contrast to the mixed-method research strategy to using ‘multi-method’ research strategy in which multiple data collection methods are employed but within either a qualitative or a quantitative study. Therefore multi-method studies are either qualitative or quantitative in nature but not both simultaneously.

3.6.4 Research Choice Summary

Yin (2009) suggests that mixed-method research forces the same questions to be shared and allows for the collection of complementary data and for the conduct of counterpart analysis. Yin (2009) further suggests that this approach allows the researcher to collect a stronger chain of evidence than can be done by employing any single method. A mixed-method research strategy was adopted as the overall approach to conduct this research. In support of mixed method research, Saunders et al. (2009, p. 153) suggest that ‘*You may wish to employ, for example, interviews at an exploratory stage, in order to get a feel for the key issues before using a questionnaire to collect descriptive or exploratory data*’.

Literature review has shown that construction site superintendents play a crucial role in maintaining the health and safety of construction workers. This research, being of an explorative nature of combining RFID and BIM technologies to improve site safety, it is vital that input from site superintendents is used. A qualitative approach will be adopted in the creation of a conceptual framework for combining RFID and BIM for site safety monitoring, using semi-structured interviews. Due to the inherent qualitative nature of interview data, the first stage of the study can be considered ‘qualitative’ in nature.

The conceptual framework will be subsequently validated using a quantitative approach by conducting a construction industry Internet survey. Literature has shown that the survey instrument is inherently associated with a quantitative approach and is an appropriate tool in social research (Saunders et al., 2009). Revisiting the differences between qualitative and quantitative approaches as outlined by Bryman (2012), table 3.3 shows the sequence and methods employed in conducting this research. As presented in table 3.3, the qualitative study will be conducted first to create a conceptual framework and followed by a quantitative study to validate the conceptual framework.

Mixed Method Approach for RFID + BIM based Construction Safety Monitoring	
<i>Qualitative Approach: Conceptual Framework Development</i>	<i>Quantitative Approach: Conceptual Framework Validation</i>
<p><i>Words:</i> Textual data will be collected using semi-structured interviews with construction site superintendents.</p> <p><i>Point of view of participant:</i> Superintendents will be asked about their opinion regarding safety on a construction site and related issues. Interviewer will try to understand personal points of view from the participants regarding monitoring construction workers.</p> <p><i>Researcher is close:</i> The researcher will conduct face-to-face interviews.</p> <p><i>Theory Emergent:</i> Conceptual framework will be developed using the results from interview data</p> <p><i>Process:</i> Data will be qualitatively coded to understand the underlying relationships.</p> <p><i>Unstructured:</i> Semi-structured interview data, by its very nature, is somewhat loosely structured. A set of interview questions will be prepared for the purpose of this research but participants will be allowed relative latitude to answer each question as they see fit. Where appropriate, the interviewer will seek further clarification</p>	<p><i>Numbers:</i> Survey data will be collected and analysed using descriptive statistical methods.</p> <p><i>Point of view of researcher:</i> The conceptual framework will be formulated from superintendents and the survey participants will be asked to provide feedback about the various sections of the framework, using Likert scale data.</p> <p><i>Researcher is distant:</i> Since this will be an anonymous Internet survey, the researcher will have no contact with individual responders.</p> <p><i>Theory Tested:</i> The conceptual framework represents a theoretical construct that was validated by the survey.</p> <p><i>Static:</i> The data represented in the results of the survey represent the perceptions of participants at that point in time.</p> <p><i>Structured:</i> All participants will be given the same specific questions that they are asked to answer and will be given a limited choice of responses to most questions, consistent with Likert scale surveys. Participants will also be allowed to provide written feedback at appropriate junctions, keeping in line with effective</p>

<p>from the participants.</p> <p><i>Contextual Understanding:</i> Every attempt will be made by the researcher to understand the context in which the participants gave a particular response.</p> <p><i>Rich Deep Data:</i> Each interview will be conducted in approximately an hours’ duration or less, giving the researcher the opportunity to gather elaborate information about site safety and the role of the site superintendent.</p> <p><i>Micro:</i> Researcher will ask the participants about specific incidents that contributed to their beliefs about safety.</p> <p><i>Meaning:</i> By evaluating responses to individual questions as well as responses to the overall questionnaire, the researcher was able to better understand the participants’ point of view.</p> <p><i>Natural Setting:</i> Each interview will be conducted at a location of the participant’s choosing, allowing them to pick a location that is most convenient for them.</p>	<p>usage of the survey instrument.</p> <p><i>Generalisation:</i> Descriptive statistics will be used to interpret the central tendencies of the survey data.</p> <p><i>Hard Reliable Data:</i> Numerical data will be used from the results of the survey to interpret the meaning.</p> <p><i>Macro:</i> The data gathered will represent the opinions of construction industry professionals at various levels within the industry and can be considered to represent a snapshot view of their opinions in regards to the proposed framework.</p> <p><i>Behaviour:</i> The data collected in the survey will be a quantifiable measure to categorise the opinions of the participants and will represent their beliefs towards site safety monitoring using RFID & BIM</p> <p><i>Artificial Setting:</i> The survey will be conducted over the Internet, which is a rather impersonal way of collecting data and represents a stark contrast to the interview format. The survey will be conducted anonymously; hence the researcher will not have any personal contact with the survey participants with regards to the survey instrument.</p>
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Table 3.3: Qualitative and quantitative strategies employed in conducting research

A proof of concept software prototype solution will be developed and evaluated in order to demonstrate that the proposed framework can be implemented on a construction site, using scenario simulations. The ‘software prototyping’ methodology will be used to create the software prototype. A ‘model’ in software engineering in many ways represents an execution plan similar to a construction plan (Ludewig, 2003). Several methodologies exist for the creation of software programs including the ‘Waterfall Model’, ‘Agile Model’ and ‘Software Prototyping’. These methodologies are often referred to as models in the software programming arena (Ludewig, 2003). Each of these models represents a holistic approach to creating software programs. From a methodological perspective the ‘Waterfall Model’ is the oldest model and represents a linear approach to programming wherein the project is broken down into several sequential stages and work at each stage is completed before work at the next stage is ready to be taken up (Yoffie, 1997). The ‘Agile Model’ is a more recent methodology in which the software project is split up into several parts and may be developed in a sequential or simultaneous manner. The ‘Agile Model’ has been compared to a puzzle where each piece is developed separately and eventually put together at the appropriate time to form the entire software (“Waterfall vs. Agile Methodology,” 2008). The ‘Prototype Model’ is considered an inexpensive way to develop and test a software before making an investment to develop a production model software (Davis, 1992). The ‘Prototype Model’ of development allows a quick turnaround time for the development of the software as well as uncovering any unforeseen implementation issues for the program (Davis, 1992). Details regarding the process of the software prototype creation are presented in section 3.10.3 of this chapter.

3.7 Time Horizons

‘Time Horizons’ speaks to the time frame available/required to conduct research. ‘Cross-Sectional’ and ‘Longitudinal’ are the two types presented by Saunders et al. (2009) in their research onion. Cross-sectional studies present the findings to a research question at a particular point in time and are generally considered to be a ‘snapshot’ view of the findings (Kail and Cavanaugh, 2008). Longitudinal studies, on the other hand, are typically aimed at understanding changes in causal relationships over a certain amount of time (Menard, 2002). Consequently, cross-sectional studies tend to be conducted over a

fixed shorter duration of time as compared to longitudinal studies that tend to be conducted over an extended period of time.

In this research, the intent is to propose a framework for monitoring construction workers using RFID and BIM to improve safety. A cross-sectional design is proposed for the creation of the framework by consulting construction site superintendents, whose responsibility it is to monitor the safety of construction workers. This is an explorative research intended to combine two technologies in order to monitor safety on construction sites and not intended to study the long-term effects of any phenomenon, hence a cross-sectional research choice is appropriate. The proposed framework is also built around two technologies that are ripe in the construction industry, as shown in the literature review. Since technological changes are frequent in society, it is therefore proposed for this study to be conducted by using a cross-sectional design. Bryman (2012) suggests that cross-sectional research is often associated with quantitative research but also acknowledges that procedures such as semi-structured interviewing represent a cross-sectional design that is quite common to qualitative design.

Additionally, this research is being conducted as part of a PhD research thesis that must meet strict university guidelines for the timely collection of data and presentation of findings. Therefore, given the time constraints and the nature of the mixed-method research, a 'Cross-Sectional' approach will be adopted. This research will provide a snapshot of data from simulations for implementing the proposed framework for monitoring construction workers by combining RFID and BIM technologies.

3.8 Data Collection

Saunders et al. (2009) identify the data collection and analysis as the most important aspect of conducting research. In relation to data collection, some key issues identified by Saunders et al. (2009) include 'Sampling', 'Secondary Data' and 'Primary Data'. In this section these issues are further elaborated and discussed in the context of the current research.

3.8.1 Sampling

Sampling is the technique by which units from a population are chosen to participate in the data collection phase of research (Saunders et al., 2009). Two techniques of sampling are available for conducting research:

- Probability or representative sampling
- Non-probability or judgmental sampling

3.8.1.1 Probability Sampling

Probability sampling implies that the units chosen from the population for the study were done so with some level of randomness associated with the selection process (Trochim, 2006). The probability or chance of choosing any unit from the population is generally equal in employing this technique (Saunders et al., 2009). Probability sampling techniques are commonly used in survey based research strategies when statistical inferences are needed to analyse data so that the results may be considered as representative of the population (Saunders et al., 2009).

3.8.1.2 Non-Probability Sampling

Non-probability sampling techniques are used when the research aim and objectives call for an alternative form of selecting the sample (Saunders et al., 2009). Saunders et al. (2009) further identify 'Purpose Sampling' as a strategy within non-probability sampling. 'Purpose Sampling' is used when the sample is chosen with a purpose in mind. In the context of this research 'Purpose Sampling' was used to select construction site superintendents in the first phase of the research. For this research, the views of construction site superintendents will be used in the creation of a framework for safety monitoring using RFID and BIM. Hence, construction site superintendents will be chosen based on availability and willingness to participate. Data from this stage will be used in the development of the conceptual framework to monitor construction workers using RFID and BIM technologies. This technique has been further classified as 'Expert Sample' by Trochim (2006) and as 'Homogenous Sample' by Saunders et al. (2009). This technique is suggested by Saunders et al. (2009) when the focus of collecting data is to get an in-depth understanding of issues. Twenty construction site superintendents will be contacted for conducting interviews. The number twenty was based on the study

conducted by Guest et al. (2006) who have shown that data saturation occurred after twelve interviews in qualitative studies.

In the second phase of this research, using an Internet survey of construction professionals, the conceptual framework will be validated. Saunders et al, (2009) suggest that the use of an internet survey is suitable when a large audience in geographically dispersed regions are surveyed. Saunders et al. (2009) suggest the use of ‘Typical Case Sampling’, also referred to as ‘Modal Instance Sampling’ by Trochim (2006), by which a typical case representative of the sample is chosen. The typical cases in this instance are professionals within the construction industry. The qualitative data used in this research will be based on the opinions of construction site superintendents. Since the research proposes an innovation for the construction industry, construction professionals within the industry with other roles such as project managers, assistant project managers and assistant superintendents will be invited to participate in the collection of quantitative data.

3.8.2 Secondary Data

Existing data when reconsidered for conducting for research is referred to as ‘Secondary Data’. A different researcher generally collects secondary data, for a different or similar purpose than the current study (Saunders et al., 2009). Secondary data can also include raw or summary data from previous research or organisational data such as payroll records, meeting minutes, etc. and governmental records such as demographical information, social and economic information (Saunders et al., 2009). The advantages of using secondary data may permit researchers to conduct studies unobtrusively, with fewer resources and allow for the conduct of longitudinal studies. However, the disadvantages of relying on secondary data include the possibility that the data is neither valid nor reliable, access may be difficult or costly and the data may have been collected with a different original purpose along with possibly being unable to fully address the issues at hand. This research aims to combine RFID and BIM technologies to affect the safety outcomes on a construction project and is inherently explorative in nature. Similar research has not been found in the literature therefore secondary data will not be used for the purpose of this research.

3.8.3 Primary Data

Data collected first hand by the researcher is referred to as ‘Primary Data’. Saunders et al. (2009) present three methods of collecting primary data including ‘Observation’, ‘Semi-Structured, In-Depth and Group Interviews’ and ‘Questionnaires’.

3.8.3.1 Primary Data Collection through Observation

Data collected primarily through observing individuals in their natural environment is a common form of data collection in social research (Sapsford and Jupp, 2006). Observation has the advantages of allowing researchers to directly gather information about the environment and human behaviour, of allowing researchers to notice issues about the environment and behaviour of subjects that may be taken for granted and are not elicited in other methods of data collection, and allow researcher to gather data about subjects that cannot participate in the study directly such as babies and young children (Sapsford and Jupp, 2006). However, limitations for using observations for gathering data include issues such as being unable to physically observe the environment or behaviour in question, participants subconsciously altering their behaviour during the observation process, misinterpreting what is being observed due to observer bias and that observation is a highly time consuming process (Sapsford and Jupp, 2006).

Saunders et al. (2009) present two forms of data collection using the observation method, namely ‘Participant Observation’ and ‘Structured Observation’. ‘Participant Observation’ has anthropological and ethnographic roots and tends to be qualitative in nature and attempts to understand the behaviour of those being observed. The observer may or may not be an active participant in the activities being observed and the observer may or may not reveal the purpose of their participation to those being observed. ‘Structured Observation’, on the other hand, tends to be more quantitative in nature, wherein the frequency of a particular phenomenon or behaviour is counted as opposed to understanding why they are occurring. For the purpose of this study observations were not considered, as the aim of this research is to monitor construction site safety by combing RFID and BIM technologies. However, observing construction workers and superintendents might have gathered useful information on a site by studying their

movement within the site and their behaviour. This method of data collection was not chosen, as it would have been time consuming, might have required several observations, would require multiple simultaneous observers as workers are dispersed throughout the site, as well as require several construction sites to be observed.

3.8.3.2 Primary Data Collection through Semi-Structured, In-depth and Group Interviews

Saunders et al. (2009) draw distinctions between three types of interviews, namely ‘Structured Interviews’, ‘Semi-Structured Interviews’ and ‘Unstructured Interviews’. Structured Interviews use a single set of pre-determined questions and the interviewer would read each question and record the answers for each of those questions. Structured interviews are used to collect quantifiable data and are referred as ‘Quantitative Research Interviews’ (Saunders et al., 2009). ‘Unstructured Interviews’, also referred to as ‘In-Depth Interviews’, on the other hand, are informal conversations where the interviewer does not have a pre-determined list of questions but instead is guided by a topic and asks questions allowing the interviewee to answer freely about events, behaviour and beliefs (Saunders et al., 2009). ‘Semi-Structured Interviews’ can be considered as occupying the middle ground between ‘Structured Interviews’ and ‘Unstructured Interviews’. In this format, the interviewer is guided by a list of themes and questions, however the order of questions may be different and some questions may be eliminated altogether, while new questions may be required, depending on the context (Saunders et al., 2009). The interviewee in a semi-structured interview has more latitude to answer questions in an open manner, however the researcher may guide the whole processes in order to get responses to all questions fully and in a timely fashion.

The use of interviews to collect data is an acceptable method in social research and the sample size is also generally acknowledged to be small (Denscombe, 2007). Semi-structured interviews will be used in conducting this research. A list of questions/themes (interview schedule) will be created for guiding each interview. The interview schedule is presented in Appendix – 4.1 of this thesis and is discussed in further detail in chapter 4. All interviews will be conducted at a time and place of convenience of each interviewee. Semi-structured interviews will be conducted to understand the role of the site

superintendent, understand safety implementation issues on the construction site, understand how superintendents keep track of workers on the site, understand their perspective of causes for safety accidents in the construction industry, and their approach to mitigate accident risks. In effect, the research will probe particular themes related to safety in the construction sites, thus making semi-structured interviews an appropriate technique to gather data. In situations when a researcher is somewhat familiar with the concepts being researched and the research focus is in a concentrated area, semi-structured interviews is a suggested data collection technique by Bryman (2012) and is in line with the interpretivist epistemological standpoint adopted in this research (Saunders et al., 2009).

‘Group Interviews’, also referred to as ‘Focus Groups’ by Saunders et al. (2009), are used when the researcher is interviewing multiple participants simultaneously. This allows the participants to agree/disagree/refine the data collected. On the one hand, this type of data collection can produce rich data in value, but it is also acknowledged that it presents problems in ensuring that all participants have an equal opportunity to present their perspective. It is possible that one or two individuals in a focus group may dominate the discussion and therefore the output generated from the focus group. Focus groups require a critical mass of eight to twelve participants to gather meaningful data, according to Saunders et al. (2009). Literature has shown that construction superintendents play a key role in the day to day operations of a construction project (Mattila et al., 1994). Logistically speaking, it would be a highly difficult task to assemble eight to twelve construction superintendents, who due to the very nature of their job description would be in a geographically dispersed region, to conduct focus groups about construction site safety issues. Hence focus groups were not used for conducting this research.

3.8.3.3 Primary Data Collection through Questionnaires

Saunders et al. (2009) describe two forms of collecting data through questionnaires. ‘Structured Interviews’ wherein the researcher is verbally asking questions to the interviewees and the use of ‘Questionnaires’ or ‘Surveys’ wherein the participants provide written responses to a list of questions. The use of a survey allows researchers to collect large amounts of data in an economical manner (Saunders et al., 2009). A survey

can contain open-ended questions as well as closed questions with a predetermined array of answers for the respondent to choose from (Fellows and Liu, 2009). The use of closed questions can provide numerical responses allowing for the use of descriptive or inferential statistical analysis, the open-ended questions allow the researcher to probe further and provide a richer meaning to the responses to the closed questions. An internet survey using both closed and open-ended questions will be used to collect feedback in order to validate the conceptual framework for this study, which will be generated using qualitative interviews with construction site superintendents.

It has been shown that the visual layout within a survey instrument has an effect on the respondents, regardless of their demographics (Stern et al., 2007). Care will be taken to ensure that questions are presented in a similar fashion and pilot candidates will be asked to view the survey and provide feedback about the layout of the questions, wording, order etc. Survey respondents will be first asked to agree to the ethical statement describing how the data will be used and their rights as respondents. In the design of this survey a short video will be shown to the respondents about the core concepts of RFID, BIM and combining the two to monitor safety of construction workers. Respondents will watch this video before proceeding to answer the questions. This is a slight variation to the approach suggested by Knight and Ruddock (2009), that a few statements be presented to the respondents to allow them to see the research aims as a guide to the respondents to answer the survey questions. The conceptual framework for monitoring construction worker safety using RFID and BIM will result in themes, which will be validated. The questions part of the survey will be divided up into appropriate sections. Within each section of the survey, a brief explanation of the theme will be presented along with any visual representation of that theme being implemented, by using a static image. Participants will provide feedback to statements based on Likert scale data, choosing between options based on an agreement rating scale, as suggested by Saunders et al. (2009). The options presented ranged from 'Strongly Disagree', 'Disagree', 'Neutral', 'Agree' and 'Strongly Agree'. The survey will validate the conceptual framework created from interviews with construction site superintendents, essentially seeking the opinion of participants regarding their agreement of the themes presented. Saunders et al. (2009) propose the use of the agreement-based Likert scale for collecting feedback about how

strongly respondents agree with a proposed statement. In each section of the sections of the survey, apart from collecting Likert scale data, participants will also be given an option to provide feedback via an open-ended text box for additional comments. The last section will provide an opportunity to the participants to comment about the overall framework. The survey will be sent to construction professionals using industry associations and personal contacts of the researcher within the construction industry.

3.9 Data Analysis

Data analysis will be conducted in a manner consistent with the collection procedures and the type of data collected. Saunders et al. (2009) present different procedures for analysing qualitative and quantitative data. This research was conducted using mixed methods; therefore both qualitative and quantitative data was collected in the process. This section provides an overview of the analysis procedures undertaken in the conduct of this research.

3.9.1 Qualitative Data Analysis

Saunders et al. (2009) indicate that qualitative data is based on expressing meaning through words resulting in non- standardised data to be developed into categories and that the data must be analysed through conceptualisation. Saunders et al. (2009) indicate that data from semi-structured interviews falls under the qualitative category and requires a qualitative analysis of the same. ‘Content Analysis’ and ‘Thematic Analysis’ are two common methods of analysing textual data. Content analysis is a qualitative method of analysing raw data as is thematic analysis, however thematic analysis only considers the qualitative nature of the data whereas content analysis generally results in quantifying the data by counting the frequency of the emergent themes and codes (Vaismoradi et al., 2013). At the core of both content and thematic analysis, data is arranged into themes or codes by categorising raw text under meaningful labels or codes. While content analysis considers the frequency of the occurrence of codes to describe the data, thematic analysis interprets the data by analysing the meaning of the codes within that context (Marks and Yardley, 2004). The data collected in this research from the semi-structured interview stage will be analysed using the qualitative technique of thematic analysis and content analysis by creating codes and labels. Since not all superintendents interviewed may

describe a certain scenario or phenomenon in the course of an interview, thematic analysis is more appropriate in the context of this research. The number of times a certain phenomenon is described by the interviewees is important in describing the importance of a phenomenon by the interviewees and will also be considered in the context of this research, along the lines of content analysis. However, it possible that only one or two interviewees may suggest a use for the proposed framework which may be significant when the framework is put up for validation, therefore justifying the use of thematic analysis. On the other hand, if a theme/issue is found to have been reiterated several times by the interviewees, it would convey the importance of the theme/issue and must be carefully considered in interpreting the data. Therefore quantitative content analysis will also be used to identify repeating themes in the interview data. The results of the thematic and content analysis will be used in formulating the framework for combining RFID with BIM.

The process of coding the data itself is further categorised by Saunders et al. (2009) as ‘Deductive Coding’ and ‘Inductive Coding’. These are closely associated with content analysis as well as thematic analysis and one method is chosen prior to starting the coding process (Bernard and Bernard, 2012; Braun and Clarke, 2006). In using deductive coding, the codes may be pre-selected prior to beginning the coding process (Ayers, 2007). Inductive coding, on the other hand, relies on the data to develop codes and is often associated with ‘Grounded Theory’ (Bernard and Bernard, 2012). In qualitative studies starting with an inductive approach, data is often coded using inductive approach (Ayers, 2007). Therefore an inductive approach will be used in the coding of the data as it corresponds with a qualitative study and also because an inductive approach was chosen for the overall study.

Each interview will be recorded in digital audio and will be later transcribed for analysis purposes. Care will be taken to ensure that all the recorded interviews are transcribed verbatim without any bias. Each interview will be read and answers to questions from interviewees will be grouped for further analysis. Codes will be created using the ‘Open Coding’ mechanism suggested by DeCuir-Gunby et al. (2011). Open coding is the process of labelling raw data under various headings so that further analysis may be

conducted to organise, categorise, quantify and identify relationships within the codes. The codes will then be carefully examined from a content analysis point of view as well as a thematic analysis point of view. Data saturation observations as well as codes/labels that are directly related to safety monitoring using RFID and BIM will be used to create a conceptual framework for combining RFID and BIM technologies to monitor construction safety.

3.9.2 Quantitative Data Analysis

Saunders et al. (2009) indicate that quantitative data aims to derive meanings from numbers, resulting from numerical and standardised data and that the data must be analysed through diagrams and statistics. The Likert data collected from the Internet survey will be used as the basis for conducting quantitative analysis in this research. The Likert data will be primarily analysed using quantitative methods, however since the survey data will also include open-ended questions, qualitative analysis will also be performed and to serve as supporting/refuting supplementary arguments for the quantitative analysis. The analysis from the Internet survey is expected to allow for the validation and/or modification of the conceptual framework, which, in turn, will be created from the qualitative analysis of the interview data.

Saunders et al. (2009) suggest that numerical data from surveys can be analysed using ‘Descriptive’ or ‘Inferential’ statistics. Descriptive statistics are used to describe the central tendency of the data as well as describe the dispersion of the data from the central tendency (Hinton, 2004). Central tendency itself is an examination of considering the values that can provide a general impression of the data (Saunders et al., 2009). Inferential statistics, on the other hand, look at the data beyond the central tendency and are used to examine relationships, differences and trends within the numerical data. Inferential statistics allow the data to be tested for strength and significance of relationships between variables (Saunders et al., 2009). Bernard and Bernard (2012, p. 551) present that “*Descriptive Analysis is about the data you have in hand. Inferential analysis involves making statements – inferences – about the world beyond the data you have in hand.*”

The quantitative analysis from the Internet survey for this research is aimed at validating the conceptual framework that will be created from the results of conducting qualitative analysis on interview data. The conceptual framework is expected to be validated/modified/refined from the data in the Internet survey. The mixed method research methodology is chosen for this research so that the quantitative data could be used to validate the conclusions made from the qualitative data. Hence, descriptive statistics are proposed for interpreting the results for the Internet survey data. Descriptive statistics provided a measure of how construction professionals viewed the proposed framework for combining RFID and BIM technologies to monitor construction site safety.

3.10 Research Phases

The research process for this project is split into three phases, as presented in figure 3.2. Each phase of the research is described in detail in this section.

PHASE	PLAN	TOOL
<div style="border: 1px solid black; border-radius: 10px; padding: 5px; display: inline-block; margin: 10px;"> PHASE 1 </div>	<div style="border: 1px dashed red; padding: 5px; margin: 10px; text-align: center;"> PROBLEM IDENTIFICATION </div> <div style="border: 1px dashed red; padding: 5px; margin: 10px; text-align: center;"> UNDERSTAND FIELD SUPERVISION AND MONITORING METHODS </div>	<div style="border: 1px solid blue; padding: 5px; margin: 10px;"> LITERATURE REVIEW <ul style="list-style-type: none"> – Site Health and Safety – RFID – BIM – Visualization </div> <div style="border: 1px solid blue; padding: 5px; margin: 10px;"> RESEARCH AIM & OBJECTIVES <ul style="list-style-type: none"> – Literature Review – Pilot Interviews – Personal Experiences </div>
<div style="border: 1px solid black; border-radius: 10px; padding: 5px; display: inline-block; margin: 10px;"> PHASE 2 </div>	<div style="border: 1px dashed red; padding: 5px; margin: 10px; text-align: center;"> DEVELOP CONCEPTUAL FRAMEWORK </div> <div style="border: 1px dashed red; padding: 5px; margin: 10px; text-align: center;"> VALIDATE FRAMEWORK </div>	<div style="border: 1px solid blue; padding: 5px; margin: 10px;"> CONCEPTUAL FRAMEWORK <ul style="list-style-type: none"> – Pilot Interviews – Semi-Structured Interviews – Aggregate Site Supervision Decision Framework – Develop Site Supervision Framework Based on Monitoring </div> <div style="border: 1px solid blue; padding: 5px; margin: 10px;"> VALIDATION OF FRAMEWORK <ul style="list-style-type: none"> – Survey – Implementation Scenarios </div>
<div style="border: 1px solid black; border-radius: 10px; padding: 5px; display: inline-block; margin: 10px;"> PHASE 3 </div>	<div style="border: 1px dashed red; padding: 5px; margin: 10px; text-align: center;"> DEVELOP LOCATION BASED SITE SAFETY SUPERVISION MODEL </div> <div style="border: 1px dashed red; padding: 5px; margin: 10px; text-align: center;"> CONCLUSIONS & RECOMMENDATIONS </div>	<div style="border: 1px solid blue; padding: 5px; margin: 10px;"> DEVELOP FINAL MODEL <ul style="list-style-type: none"> – Virtual Prototype Development – Scenario Simulation using Virtual Prototype </div> <div style="border: 1px solid blue; padding: 5px; margin: 10px;"> FINAL WRITE-UP </div>

Figure 3.2: Research Process.

3.10.1 Phase 1: Problem Identification

A critical review of literature is often one of the first stages of an academic research endeavour (Yin, 2009). The previous chapter presented a critical review of literature regarding the various issues associated with this research. A wide-ranging literature review was conducted prior to establishing the aim of this research. The role of a construction superintendent to supervise workers was examined. The use of contemporary technologies such as RFID and BIM within the construction industry was studied. The

increasing use of digital visualisations in the construction industry processes as well construction academic research was studied. Literature review was conducted into the safety practices of the construction industry. Construction industry professionals were consulted in the way of pilot interviews to test the idea of monitoring the movement of construction workers for enhancing jobsite safety. The researchers' personal experiences of working in the construction industry were also contemplated. The findings from the literature review, the pilot interviews and the researchers' personal experiences were used in developing the research aim and objectives for this study.

3.10.2 Phase 2: Conceptual Framework Development and Validation

The next phase of the research will be conducted to develop and validate a framework for monitoring the movement of construction workers using RFID and BIM. The creation of the framework is expected to be done through data gathered from interviewing construction site superintendents. A questionnaire will assist with the conduct of semi-structured interviews (Appendix – 4.1). The questionnaire is designed to understand the role of site superintendents in executing a construction project, about their role in monitoring safety of construction workers, about the role of the construction companies in maintaining health & safety of workers and to understand how they perceive the location of construction workers within a construction site to implement safe practices. Issues regarding near miss accidents and congestion will be probed. Superintendents will be asked about situations where they had safety incident(s) occur on their jobsites and how they could have been prevented. Superintendents will be asked about how they keep track of the location of visitors within a construction site to manage safety. Finally, superintendents will also be asked about the possibility of using electronic means to monitor construction workers within the jobsite and were asked to elaborate on how they viewed using such a tool, if it existed. Pilot interviews will be conducted to test the themes and categories of the questionnaire and further refine the questionnaire. Semi-structured interviews with construction site superintendents in the US will be conducted. The interviews will provide an intricate perspective of the role a site superintendent plays in monitoring the health & safety of workers on a construction site. A qualitative analysis of the interview results will lead to the creation of a conceptual decision support framework, for site safety monitoring by combining RFID and BIM technologies.

An Internet survey of professionals in the construction industry will be conducted to validate the conceptual framework. The survey will be created with the intent of validating the conceptual framework emerging from the interview results. In an effort to provide some background for the research, a short video will be created and shown to the survey participants describing the major themes and concepts of the framework and associated technologies. Survey participants will then be asked to rate the various themes presented in the framework, on a Likert scale based questionnaire. Participants will also be provided with opportunities to give written comments about each theme/category. The survey itself is divided into appropriate sections for each of the categories that emerge in the conceptual framework along with a section seeking feedback from the participants about the overall framework.

3.10.3 Phase 3: Development of Software Prototype and Evaluation

This research proposes a framework for implementation on a construction site. The implementation of the framework is expected to be done by using a software solution. By developing a prototype, the feasibility of a full scale implementation may be better understood (Ambysoft, n.d). It has been found that practical suggestions can be made to the final version of the software, by developing and testing a prototype (Alavi, 1984). Therefore, in the final phase of this project, a software prototype solution to integrate RFID and BIM will be developed. The development of the software prototype will use the ‘Software Prototyping’ model for designing and creating software programs. In the context of this research, the intent is not to create a software program but rather to test and demonstrate the implementation of the proposed framework for tracking construction workers using RFID and BIM. Therefore the creation of a software prototype using the ‘Prototype Model’ will be employed to test the framework in action to track construction workers movement on a simulated site as proof-of-concept to monitor construction workers using RFID and BIM. The prototype solution will be used to conduct scenario-based simulations. These simulations will demonstrate the effectiveness of the proposed framework and the prototype virtual environment.

3.11 Research Reliability

Reliability of research speaks to whether consistent results would be obtained if the data collection procedures are repeated (Saunders et al., 2009). Trochim (2006) states that the concept of reliability cannot be accurately measured but can only be estimated. Saini and Shlonsky (2012), given the interpretive nature of qualitative studies, i.e., knowledge is created and that it is contextual as opposed to being discovered, point to researchers within the field of qualitative research who find no relevance to the repeatability question, while also pointing out that other researchers have made attempts to improve the quality and rigor of qualitative researcher. Saini and Shlonsky (2012, p. 115) acknowledge that there is no consensus within the research community regarding this issue, but nevertheless recommend three things to ensure reliability in qualitative research:

- *Use of quotes and examples to support themes*
- *Consistency of themes and quotes*
- *Transparency of research process*

Moreover, Elo and Kyngäs (2008) suggest that demonstrating a link between the results and the data is imperative in increasing the reliability of qualitative research, which requires describing the analysis process in reporting the results in as much detail as possible, i.e. audit of the decision trail.

This research will use quotes and examples to support the themes emerging from the interview data as well as responses from the open-ended questions in the survey. The interview data represent a qualitative approach to the study, whereas, the survey results represent a quantitative approach. This represents a mixed-method approach used in this study. By using the mixed method approach, it will enable the survey results to complement and uphold the findings of the results from the interviews conducted in the creation of the proposed framework. The methods and processes used throughout this research will be plainly and accurately described in this thesis.

3.12 Research Validity

Newman and Benz (1998, p. 27) say that “*Research outcomes are of no value if the methods from which they are derived have no legitimacy. The methods must justify our*

confidence. Those who read and rely on research outcomes must be satisfied that the studies are valid, that they lead to truthful outcomes". Several strategies are suggested by Saini and Shlonsky (2012) to ensure that validity of the research, including 'Triangulation'. Triangulation is the process of collecting data from multiple sources to ensure that the data is consistent (Saunders et al., 2009). Jick (1979, p. 604) states that '*In all the various triangulation designs one basic assumption is buried. The effectiveness of triangulation rests on the premise that the weaknesses in each single method will be compensated by the counter-balancing strengths of another.*' In this research, literature review, interviews with site superintendents and a survey of construction industry professionals will be used in providing multiple data sources in formulating the framework for site safety monitoring using RFID and BIM. These are all acceptable forms of data in mixed-method research, thereby increasing the accuracy of this study. The consistency can be gleaned from the fact that the conceptual framework will be the result of questions posed to construction site superintendents in face-to-face interviews, and that the questions themselves were the result of the literature review. Conducting an Internet survey, in the quantitative phase of the study, will validate/refine the results from the interview data, in the qualitative phase of the study.

3.13 Summary

In this chapter the research design and methodological constructs used for this research were presented. The Saunders et al. (2009) research onion model was used to justify the choices adopted. In this chapter the philosophical underpinnings, the approaches, strategies, choices, time horizons, techniques and procedures used for this research were identified and justified. Several sources of literature were critically evaluated in justifying the choices made for the various research paradigms described in this research. The techniques used for data collection and analysis for this research were identified as well as justified for their adequacy. The three phases in which this research will be conducted were presented. The chapter also addressed how this research dealt with issues of reliability and validity of this research. The next chapter, chapter 4, presents the process undertaken leading to the formulation of a conceptual framework to combine RFID and BIM technologies to monitor safety on construction sites.

CHAPTER 4

CONCEPTUAL FRAMEWORK

4.1 Introduction

In chapter 3, a brief overview of the various philosophical paradigms for conducting research was presented. The philosophical stance chosen for conducting this research was presented and justified. The methodological tools adopted for conducting this research were also presented and justified as well. In this chapter the results from conducting semi-structured interviews with construction site superintendents is presented. The analysis of the interview data is presented, along with the procedures undertaken to interpret the data, leading to the development of a conceptual framework to monitor the movement of construction workers using RFID and BIM for safety purposes.

4.2 Data Collection Procedures

As discussed in Chapter 3 an interview schedule was prepared to conduct semi-structured interviews with construction site superintendents. The interview schedule itself is presented in Appendix – 4.1 of this thesis. The interview questionnaire was aimed at understanding the aggregate role of the construction superintendent apart from questions relating to maintaining health and safety on the construction site. Although the questions were not presented to the interviewees in any category, the interview schedule included questions on the themes represented by these sub-titles: *‘Duties of Construction Superintendent’*, *‘Site Safety Issues from a Superintendent’s Perspective’*, *‘Location of Construction Workers on Site’*, *‘Safety Incident History and Prevention’* and *‘Superintendents’ Perspective of RFID + BIM Solution’*. Superintendents’ perspective of a typical workday on the construction site and the key responsibilities of their role were addressed in the interview schedule. The policies of construction companies relating to safety issues were explored. The role of the construction site superintendent as it relates to safety was explored. A question to understand the percentage of time a superintendent spends actually walking the various areas/zones within the construction site, on a typical day were included. Superintendents were asked about how they know the location of workers and whether it is even important for them to know the location of workers within the construction site. Superintendents were asked about how they handle situations when there are too many people on the construction site. Questions concerning the location of workers within the construction site and its relationship to the decisions a superintendent has to make were included in the schedule. A question regarding instances when the

jobsite may be overcrowded and how the superintendent handles these situations was explored. Specific safety incidents or near miss accidents that may have occurred in the experience of individual superintendents and how those incidents might have been prevented by thinking about it in retrospect were explored. The interview schedule included a question about how superintendents address situations when there are specifically hazardous activities taking place in the construction site such as removal of temporary shoring or high-rise construction. Finally, superintendents' perspective about the proposed solution for tracking the movement of construction workers using RFID and BIM was explored. The final question involved showing the interviewees a few illustrative figures of the proposed RFID and BIM solution to track workers within the construction site. The researcher had informal discussions with two retired construction superintendents about the study. In part this was done as an exercise to test the questions in the interview schedule. Based on feedback from these discussions the wording of the final questionnaire was modified for clarity and the sequence of questions was also slightly altered. The initial discussion also contributed to the inclusion of illustrations depicting the tracking of workers using RFID and BIM in asking the final question of the interview schedule.

Initially twenty construction site superintendents were contacted for conducting interviews. The number twenty was based on the study conducted by Guest et al. (2006) who have shown that data saturation occurred after twelve interviews in qualitative studies. Nineteen construction site superintendents agreed and were eventually interviewed in the way of data collection. Each interviewee was given a choice of time and place of their convenience for conducting the interview. Fifteen of the nineteen interviews were conducted on the construction site of that superintendent and the rest were conducted in the corporate offices of those superintendents. Each interview lasted approximately 35 minutes to an hour. Each interviewee was presented with the 'Interview Consent Form' that was approved through the University of Salford Ethical Research procedures. All interviewees consented to being interviewed for the research and signed the consent form. All interviews were conducted within a 30-day time span. All interviewees were asked the same 10 questions. All interviews were tape recorded and later transcribed from the same audio recordings. Aside from a few minor grammatical

corrections during the transcription process, the interviews were transcribed in their entirety from the audio recordings. These nineteen construction superintendents represented thirteen construction companies within the South-eastern United States. The companies are a diverse representation of practices regarding safety, as is evidenced by their annual volume. A couple of companies represented by these superintendents had an annual volume of about \$100 million, all in the same geographical region, whereas a couple of them are part of very large construction conglomerates doing more than \$5 billion each in annual global revenues. The rest of the companies all performed over \$200 million in annual revenue and had offices spread in the South-eastern United States.

4.3 Data Analysis Procedures

Atlas.Ti, a qualitative research data analysis software tool was used to analyse the interview data. The software allows for the creation of a ‘Hermeneutic Unit’ to add various types of data for the analysis process. The term ‘Hermeneutic’ is typically associated with the interpretation of qualitative data such as textual data (Laverly, 2003). However, in the context of the Atlas.ti software, a ‘Hermeneutic Unit’ essentially means a new file to which data may be associated, such as text, audio, figures, etc. The transcribed interviews as well as the audio recordings were imported into the software. Answers for each question from all the interviews were categorised into ten separate documents and were also imported into the software. Owing to reasons described in the ‘Research Design and Methodology’ chapter, thematic analysis as well as quantitative content analysis techniques was used to analyse and interpret the data from the interviews. The thematic analysis process consisted of first reading all the answers for each individual question. The researcher then created several codes for the data using the ‘Open Coding’ process, which is an acceptable method to report qualitative data from interviews (Weston et al., 2001; DeCuir-Gunby et al., 2011). Each response was then read again and codes were assigned to each response. On several occasions additional codes were created based on individual responses. On a few occasions when the data appeared to be contradictory, the audio recordings were re-heard to verify that the transcription process was accurate. This iterative process of coding interview data is suggested by Weston et al. (2001) and Braun and Clark (2006). Once the coding process for all ten questions was completed, the researcher read all the codes and associated quotes and

organised the codes under related themes. These themes were revisited to ensure that the data was consistently categorised. Braun and Clark (2006) suggest this iterative process for organising related codes into categories or themes. The results of this thematic analysis were diagrammatically represented by creating network diagrams showing categories, themes and codes. This type of presenting the analysis using network diagrams is a method of organising the data under relevant themes/topics (Attride-Stirling, 2001). The network diagrams were created using open source mind-mapping software called 'FreeMind' (freemind.sourceforge.net).

In the conduct of the quantitative content analysis, a copy of the hermeneutic unit used in the thematic analysis was created. The existing codes from the thematic analysis were deleted and new codes identifying were added, again using the 'open coding' process. The data was again analysed to see repeating themes within the codes and occasionally some codes were combined when the essence of the text seemed to indicate a particular theme or issue already identified by another code. The data was further queried to count the number of times each code was used within the context of a particular question. This information is presented in tabular form within this chapter of the thesis. Results from the content analysis are categorised by frequency of 'codes' appearing within the data analysis process. Codes were classified into green coloured cells when they appeared in more than 50% of the responses, in yellow coloured cells when they were heard from more than quarter but less than half of the respondents and in grey coloured cells when they were heard from less than a quarter of the respondents. Only codes occurring multiple times were included in the content analysis, as individual themes/codes were creating using the thematic analysis techniques. Corbin & Strauss (2008, p. 319) advise the cautious use of quotations in the presentation of results from interview data and suggest "... quotes do add interest and provide evidence for sceptics, therefore a good sprinkling of them throughout a research report is important". In this section relevant verbatim quotes from the interviews with construction site superintendents are also included.

4.4 Frameworks and Decision Support Systems

The Oxford dictionary defines the word ‘Framework’ as “*A structure made of parts joined to form a frame*” (Oxford English Dictionary, n.d.). Three different types of frameworks are presented by Eisenhart (1991), namely ‘Theoretical Framework’, ‘Practical Framework’ and ‘Conceptual Framework’. Eisenhart (1991, p. 207) suggests that a ‘Practical Framework’ “*guides research in “what works” in the experience or exercise of doing something by those directly involved in it*”. A conceptual framework has been described as a collection of broad ideas in a particular field of study and presented in a structured manner (Reichel and Ramey, 1987). More explicitly, a conceptual framework has been defined by Maxwell & Loomis (2003, p. 253) as consisting “*of theory (or theories) relevant to the phenomenon being studied that inform and influence the research*”. Theoretical framework and conceptual framework have been used interchangeably in the literature (Berman and Smyth, 2013). However, Berman and Smyth (2013) assert that the ‘Conceptual Framework’ is generated during the research and is an outcome of that research and must be tested as it may be considered a new conception. If the conceptual framework is validated by either application or scholarly review, then the resulting framework may be considered as a ‘Theoretical Framework’ (Berman and Smyth, 2013).

Trafford (2003) argues that a PhD candidates’ eligibility to pass the viva is often measured by their ability to conceptualise the research and think in abstraction regarding the key issues being studied. Bryman (2003), however, suggests that concepts do not have to be thought about in an abstract manner to the extent that they lose connection with reality. A similar argument is also made by Scriven (1985), who suggests a practical research approach in support of research that can be meaningful to practitioners, in his case to educators and students. Further justifying this approach for research, Scriven (1985, p. 57) claims that the “*...the search for understanding sometimes yields solutions to practical problems*”. In the conduct of this research, Scriven’s approach is adopted in proposing a site safety-monitoring framework using RFID and BIM. However, the importance of theory is certainly not discounted in this study as evidenced by the philosophical and methodological underpinnings presented in Chapter 3. The importance

of theory for this research is also implicit in the critical analysis of literature, which examined several theories, related to the issues concerning this research.

Punch (2000, p. 54) suggests that “*Quantitative designs typically have well-developed pre-specified frameworks, whereas qualitative designs show much more variability, from clear pre-specified frameworks, to ‘first approximations’, to no pre-specified framework at all*”. This is also consistent with Saunders et al (2009) who state that an inductive approach could result in the development of theories based on the data collected and can be considered much more ‘grounded’ in reality. Saunders et al (2009) acknowledge that in certain circumstances, inductive studies may not have a conceptual framework or pre-determined theories at the outset of conducting research. In the conduct of this research it is proposed to develop a conceptual framework following the initial stage of data collection and analysis of interviews with construction site superintendents.

An initial framework for site safety monitoring is conceptualised in this Chapter, based on the results of conducting interviews with site supervisors and through an analysis of the data. This framework is referred to as a ‘Conceptual Framework’ as it is conceived from the analysis of the interview data, which is based on the interpretation of the researcher and not validated. This framework is subsequently validated in the following chapter, a strategy similar to the one proposed by Berman & Smyth (2013). However, it is also acknowledged that the conceptual framework proposed in this research will not be an abstract representation of the research as suggested by Maxwell & Loomis (2003) but would be much closer to the practical framework as suggested by Eisenhart (1991).

Power (2002, p. 1) defines decision support systems (DSS) as “...*interactive computer-based systems that help people use computer communications, data, documents, knowledge, and models to solve problems and make decisions*”. The research conducted in this thesis proposes to develop a decision support system prototype for monitoring the safety of construction workers by the site superintendent. The system proposed is based on combining BIM and RFID technologies. The DSS prototype will be developed based on the theoretical framework, which will be developed based on the feedback from construction professionals. Literature has shown that the construction site can be chaotic

environment where hazards are continuously shifting, reflecting the changes in the type of work, materials and equipment being used (Abdelhamid and Everett, 2000). Specific contextual situations that require the site superintendent to make a decision regarding the safety concerns of a worker(s) based on their location within the site will be considered in the development of the DSS prototype.

The terms ‘decision support system’, ‘framework for decision support systems’ and ‘decision support system framework’ were found in the literature. These terms were used to describe either the DSS directly or the creation process of a specific DSS or the creation of DSS systems in general. For example, Chau et al. (2003) described the development of a DSS and the application prototype for their study entitled “*Application of data warehouse and decision support system in construction management*”. Sprague Jr. (1980) presented a framework for describing the development process of DSS’s in general in the study titled “*A framework for the development of decision support systems*”. In the study titled “*A decision support system framework for purchasing management in supply chains*” Lindgreen et al. (2009) describe the DSS itself and proceeded to present an implementation of the DSS using a prototype. Noran (2009) describes the creation of a DSS in the study entitled “*A decision support framework for collaborative networks*”. These examples indicate that the terms ‘Decision Support System’ and ‘Decision Support Framework’ have been used interchangeably in the literature to describe a DSS. This thesis adopts the use of the term ‘Decision Support Framework’ in discussing the theoretical basis for developing a DSS prototype to monitor the safety of construction workers using a combination of RFID and BIM technologies. Section 4.7 of this chapter and its sub-sections explicitly discuss how aspects of the framework assist the superintendent in making decisions related to worker safety through the DSS prototype.

4.5 Findings

The responses to the questions in related issues were combined to reflect the themes and codes emerging from the data analysis, about each particular issue. ‘Duties of Construction Superintendent’, ‘Site Safety Issues from a Superintendent’s Perspective’, ‘Location of Construction Workers on Site’, ‘Safety Incident History and Prevention’ and

‘Superintendents’ Perspective of RFID + BIM Solution’ are the titles of the following subsections, under which the results of the interview data analysis, i.e. themes, subthemes, etc. are presented.

4.5.1 Duties of Construction Superintendent

The site superintendent plays a key role in the implementation of safety on the construction site (Flin and Yule, 2004). Maintaining productivity is also an important part of the site superintendent’s responsibilities (Arditi, 1985). A comprehensive picture of the superintendents’ role in the day-to-day activities of the construction site has not been found in the literature review. Hence, questions to describe a typical workday and their responsibilities as a site superintendent were explored. These questions were asked to understand the various roles of a construction superintendent and ascertain the superintendents’ priorities as seen by each individual interviewee.

The results indicate that superintendents have multiple issues that they have to monitor/administer in the course of a construction project. These themes were classified under the labels shown in Figure 4.1, namely: ‘*Safety*’, ‘*Production*’, ‘*Quality*’, ‘*Communications*’, ‘*Coordination*’ and ‘*Schedule Management*’. The ‘*Other*’ theme was created to show codes that did not clearly fit into any of the identified themes. In the presentation of the findings, the themes are split into separate figures, as it was not possible to fit all of them in a single page and for the data to appear legible. Therefore splitting Figure 4.1 in detail view was necessary and is also not a reflection of any hierarchy within the themes.



Figure 4.1: The various duties of a construction superintendent

The themes identified under the ‘*Safety*’, ‘*Production*’ and ‘*Schedule Management*’ labels are presented in Figure 4.2. Among the issues described under the ‘*Safety*’ theme, superintendents identified a number of issues including safety meetings with various stakeholders in the project such as workers, foremen, subcontractors and anyone else visiting the site. The superintendents indicated the need to have discussions with each of them about issues concerning safety. The superintendents, on a daily basis closely monitor safety as an issue by ensuring that the workers are wearing proper PPE, are working safely and by enforcing safety rules when necessary by giving safety citations for those workers violating the rules. Safety analysis is conducted for tasks that are expected to take place each day. Equipment on the site is also checked frequently with any safety concerns. Superintendents also rely on flagmen to monitor the movement of people and equipment in certain areas within the site. Barricades and flags are used to prevent / warn people from entering into certain areas of the site. They mentioned that they relied on ‘Red-Tape’ (do not enter) boundaries and ‘Yellow-Tape’ boundaries (enter-with-caution). Comments were also made about the negative impacts safety incidents can have on the economy and productivity on the construction site.

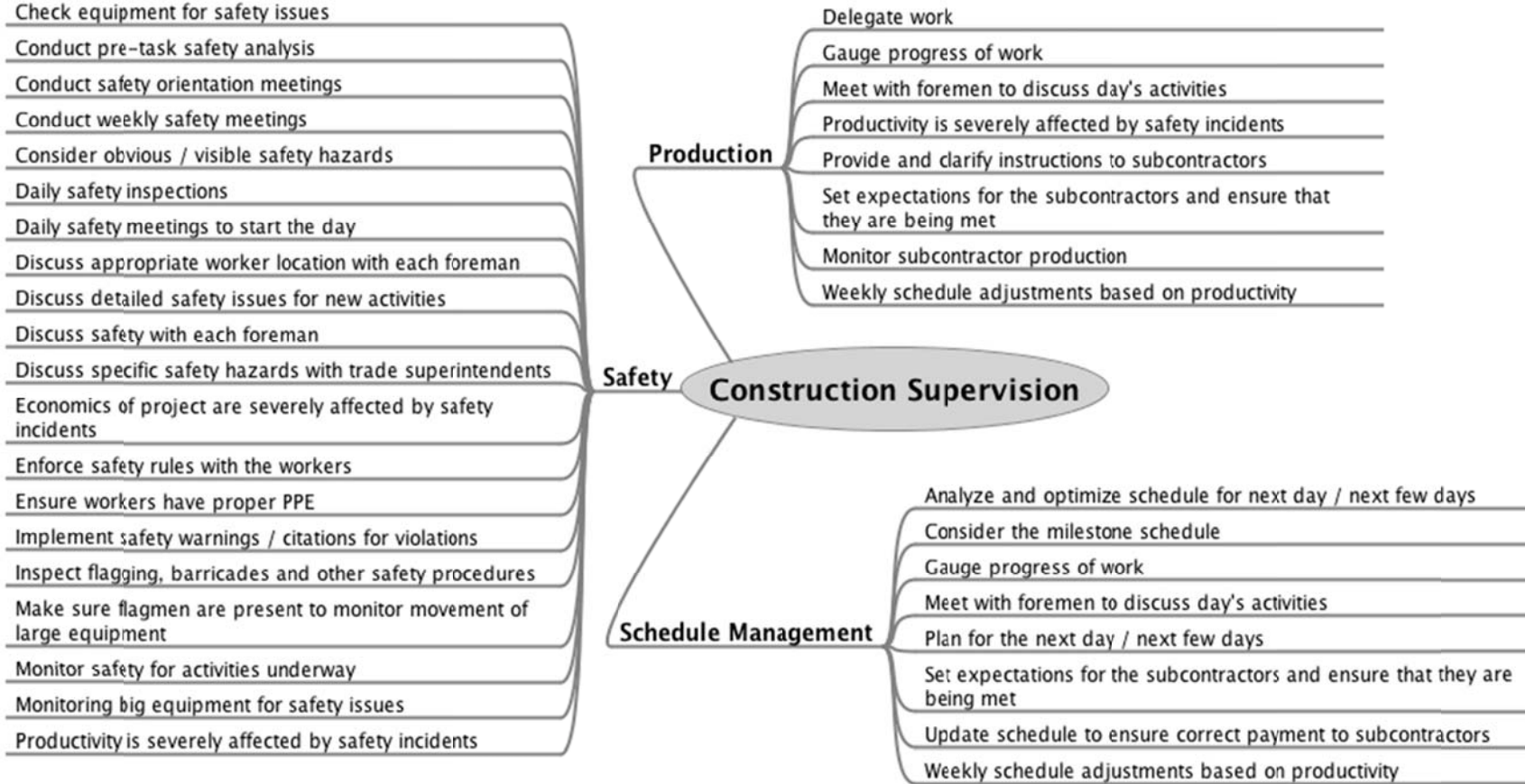


Figure 4.2: Superintendent duties for 'Safety', 'Schedule Management' and 'Production'

From the '*Productivity*' perspective, superintendents are in charge of delegating the work and monitoring the progress of the work. Superintendents communicate with the foremen, subcontractors and workers regarding expectations for activities and monitor the same to ensure that they are being met. Schedules are managed by the superintendents on the construction site, based on a host of issues such as material availability, subcontractor availability, weather etc. Adjustments to the schedule are made, based on the productivity of workers and subcontractors. Superintendents also update the schedule to make sure that the bills are paid and received correctly. Superintendents rely on milestone schedules and short-term schedules to ensure that work is progressing within the context of the larger project schedule. Unique codes generated from the data about '*Communications*', '*Quality*' and '*Coordination*' are presented in Figure 4.3, along with miscellaneous codes created. On the '*Communications*' issue, superintendents communicate with various stakeholders on a construction project including the design team and the project management staff. Responsibilities include documenting the activities on site in daily reports along with record keeping of material deliveries etc., Superintendents are expected to fill in the gaps where possible when there are gaps in the construction plans and specifications. From a '*Coordination*' perspective, superintendents work with the subcontractors to ensure that the site is not crowded and that the movement of workers and trades is conducive for productivity by allowing trades an un-restrained access to areas of the site where work is taking place.

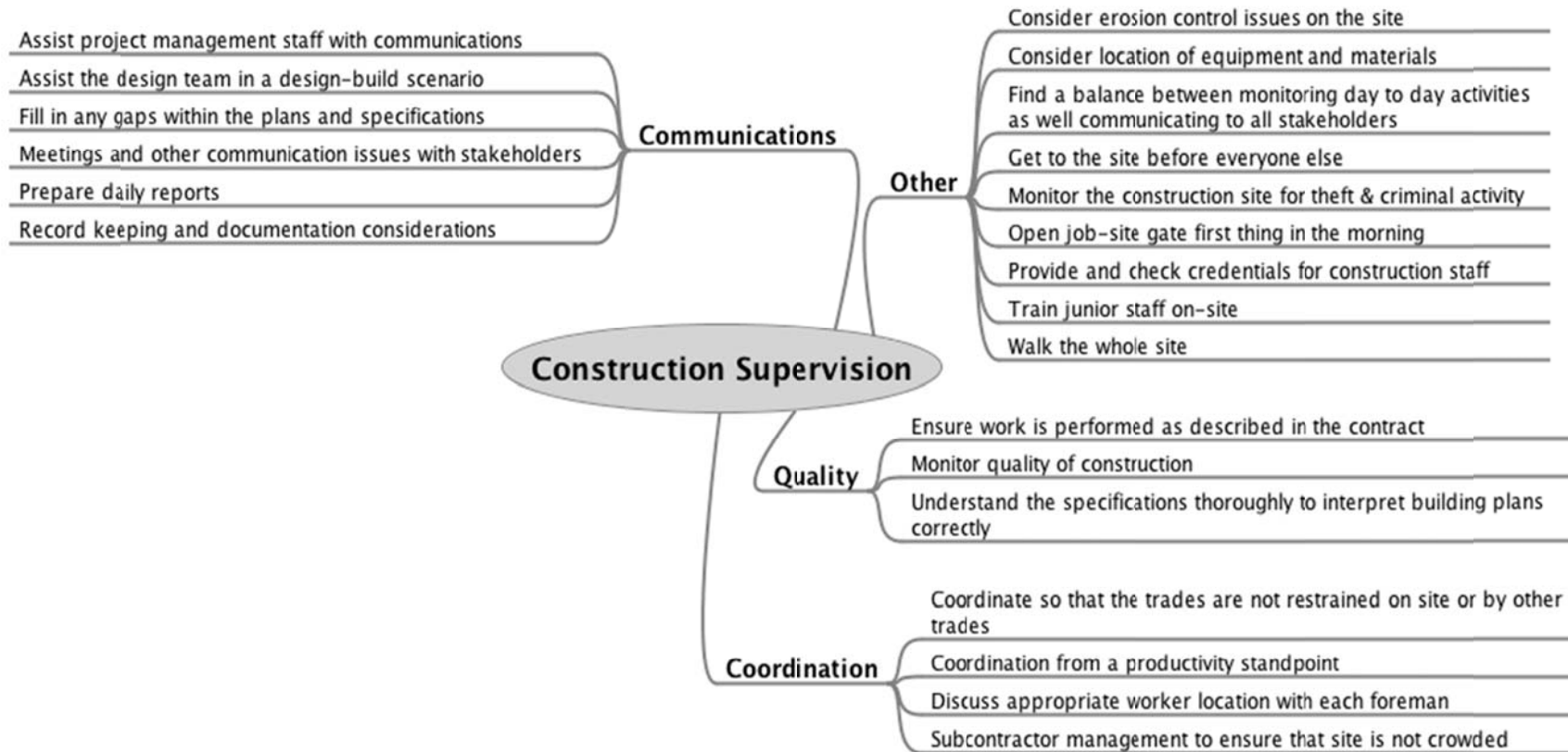


Figure 4.3: Superintendent duties for 'Communications', 'Quality', 'Coordination' and other issues

Superintendents are responsible for ensuring that the quality of construction is performed according to the terms described in the contracts, drawings and construction specifications. Essentially, superintendents have to continuously monitor the progress of construction activities to ensure that completed work is up to the required quality or better. Superintendents are also responsible for other issues such as erosion control, training junior staff, material & equipment management, staff credentialing and have to watch for theft and criminal activities on site. Superintendents are typically the first ones to get on site and open the gates before everyone else gets to the site.

As indicated earlier, the data was again analysed from a quantitative content analysis perspective to identify repeating themes among the construction site superintendents interviewed. These themes are presented in Table 4.1. The results indicate that more 50% of the superintendents identified that '*Safety*', '*Schedule Management*', '*Subcontractor Management*', '*Production*', '*Quality*', '*Coordination*' and '*Monitoring the Site*' as key responsibilities of the their job. Between 25% to 50 % of the interviewees reported that '*Safety is number one*' and also mentioned that '*Material Management*', '*Communication*', '*Problem Solving*' and '*Meetings*' were also important aspects of their responsibilities.

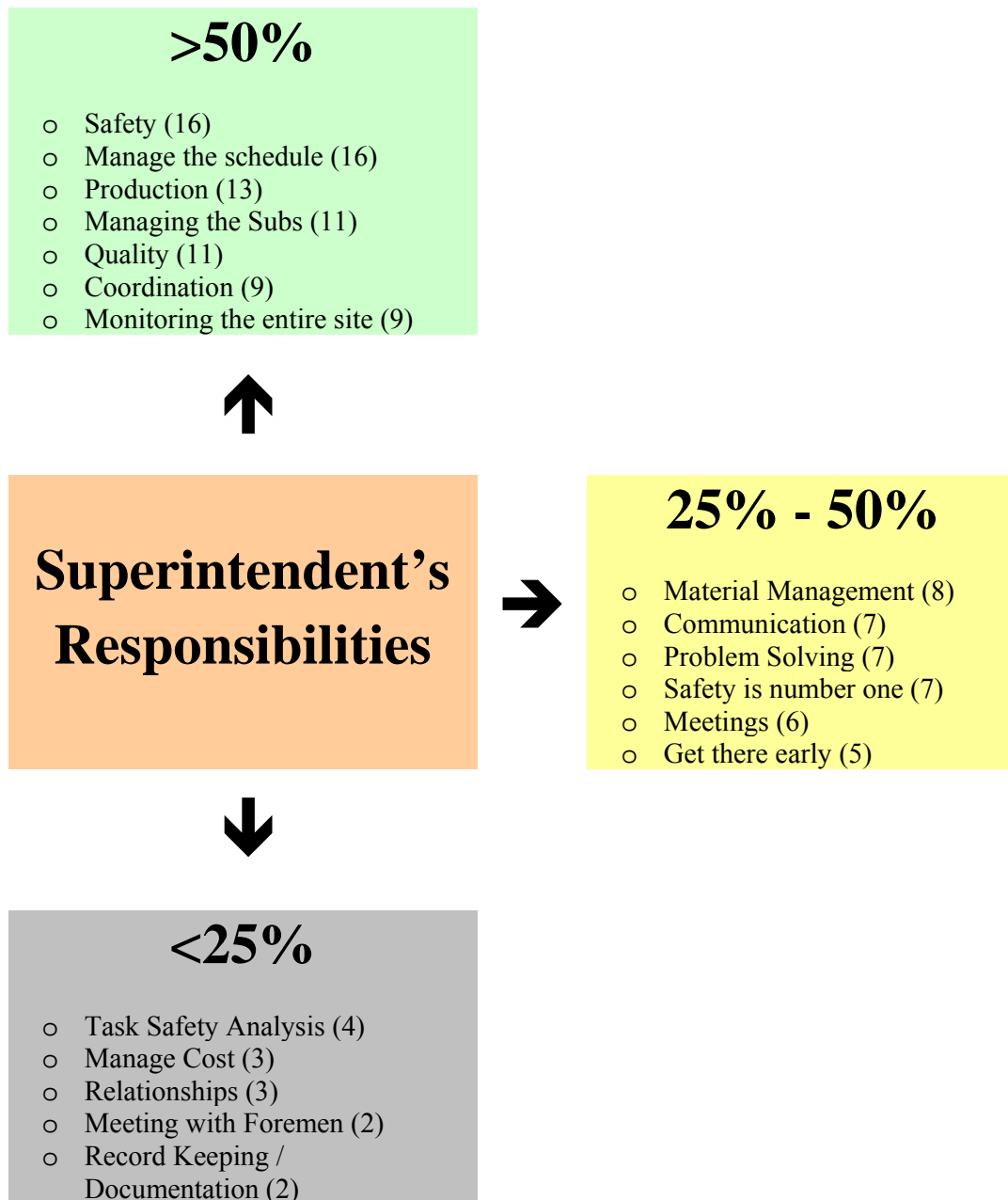


Table 4.1: Construction Superintendents' Perspective on Superintendent Responsibilities.

In summary, based on the analysis of the interview responses, every aspect of a construction jobsite is the responsibility of the construction superintendent, either directly or indirectly. Production control, schedule management, safety, quality,

subcontractor management, construction coordination and site monitoring were identified as the primary responsibilities of a construction superintendent by more 25% of the interviewees, as evidenced by the quote: *“As the superintendent in charge, you are responsible for everything going on out there. So the traditional ones you’ve got schedule, quality, safety, budget and owner’s satisfaction.”* Some superintendents indicated that material management, communication with various stakeholders, attending meetings and solving problems as they come up were also a part of their responsibilities. Several superintendents spoke about getting to the site before the workers and ensure that site conditions are conducive for the work to be performed on that day. The interviewees did not see one aspect of the job as being more important to another aspect but seven of the nineteen mentioned that ‘Safety is number one’, as evidenced by this quote: *“Well duties are pretty simple: Cost and schedule are the main two and the top one is safety. I kind of run them all together. Those responsibilities come with a lot of a, b, c’s underneath that because of the many activities that are going on within a job-site.”*

Some contractors self-perform some aspects of a construction project such as concreting; however, sub-contractors, who are contractually bound to the General Contractor (GC) rather than the owner, in most cases, do the majority of the work on a construction project. The superintendent, thus, has direct control over field personnel that represent the GC and has indirect control over field personnel of various subcontractors. Monitoring the rate of production and quality of work of all field personnel is a big part of the day-to-day responsibilities of the site superintendent. Superintendents see safety as the one thing that could affect the quality, schedule, morale, cost and overall success of a construction project, and thus, consider it as a key responsibility (Toole, 2002). Apart from constantly monitoring the progress of construction, superintendents spend a considerable amount of time planning upcoming work by coordinating with various trade contractors. The material and equipment needed by subcontractors to perform their work and the locations they will be performing the work are managed by the superintendent. Superintendents also have responsibilities that involve documenting the progress of work among other things. These documents are subject to be inspected by the home office and occasionally the

owner. In summary, superintendents see themselves as the ‘Go to person’ for all issues related to construction, as evidenced by the data presented.

4.5.2 Site Safety Issues from a Superintendents’ Perspective

Every construction company has a different level of commitment towards site safety and their own unique approach to implementing it on the construction site (Teo et al., 2005). The same can be said of construction site superintendents (Hewage et al., 2011). Therefore questions to understand the safety procedures and practices adopted by each of these companies and the superintendents themselves were included in the interview. The approach to safety from one construction organisation to another can vary. The results for the question regarding how their companies prepared them to handle construction safety are presented in Table 4.2 and in Figures 4.4, 4.5.

The responses to this question indicated that training was the corner stone of every company’s policies when it comes to safety, which is illustrated by the quote: *“Everything starts with training and it is continuous training. We do our own in house training. We are constantly updating our safety manual. Our safety program is more stringent than OSHA’s safety program.”* Construction companies provide continuous in-house safety training and provide task specific training to workers for tasks such as excavations etc. Some construction companies even go to the length of conducting quizzes (assessments) after the training is completed. Safety officers discuss industry wide safety incidents with their workers. Safety certification is another important area that companies spend resources on. The Occupational Safety and Health Administration (OSHA) provide safety training for construction personnel in the United States. Almost all companies required their superintendents to have 30-hour OSHA safety cards. A few companies required only 10-hour OSHA safety cards. These safety cards represent the level of formal safety training the cardholder has attended. OSHA prescribes the contents of the training itself and the trainers have to be certified by OSHA as well. The training contents for the 10-hour card are designed for entry-level workers and the contents for the 30-hour card are designed for superintendents and safety officers.

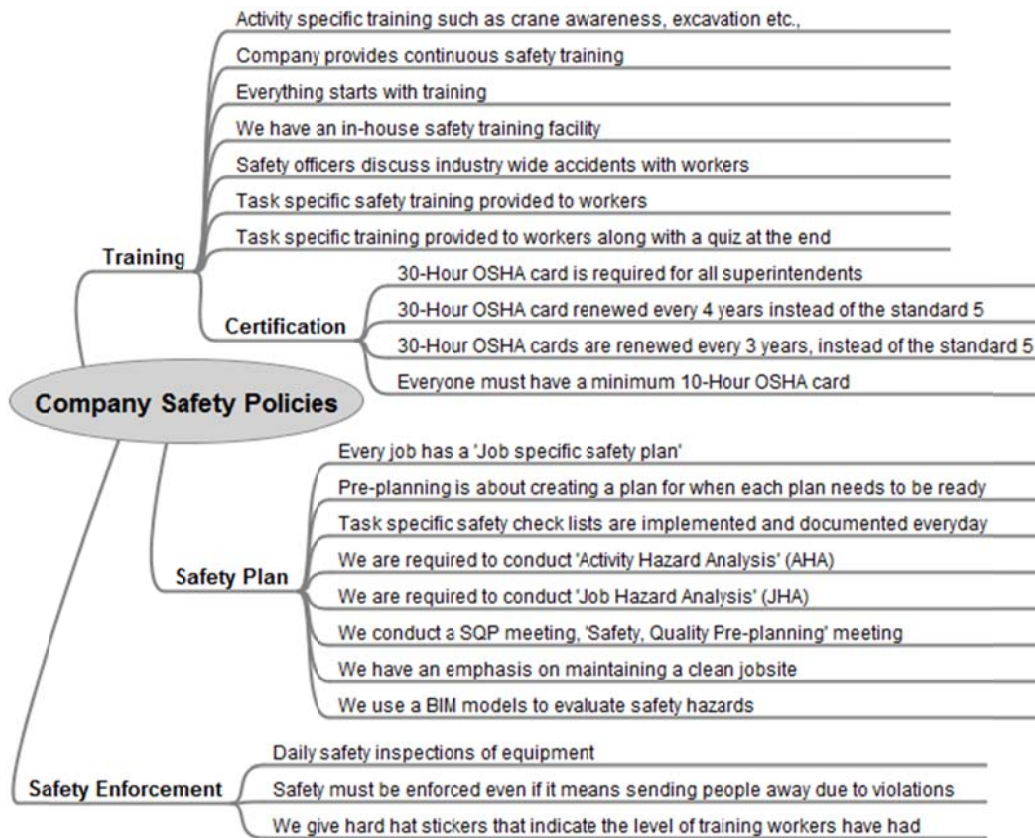


Figure 4.4 Company safety policies for ‘Safety Training’, ‘Safety Plan’ and ‘Safety Enforcement’

Interviewees described strict company policies that required them to keep up with their training certifications in order to continue to supervise. Some companies require their workers to renew their safety certifications on a three or a four-year basis, as opposed to OSHA prescribed five years. One quote that depicts these policies is: “All of our foremen and superintendents are required to have a 30-hour OSHA certification. You are required to keep up with it every 3 years. You are required to have specialized training based on your responsibilities, such as specialized training for forklift operators, other required training includes scaffold training and even our hourly workers are trained every month in some aspect of construction, whether it is confined space or lock-out-tag-out for electrical systems.”

‘Planning for safety’ also emerged as a common theme among many of the construction companies. Several companies required their superintendents to start each day by conducting a ‘Task Safety Analysis’ (TSA) also called by some companies as the ‘Activity Hazard Analysis’. A TSA is where every superintendent, foreman and subcontractor superintendent discusses, with their respective field personnel, the activities taking place that day, the hazards involved and how to mitigate them. Some companies also conducted a ‘Job-Specific Safety Analysis’ (JSA). Several experienced superintendents, sometimes referred to as the ‘General Superintendent’, typically conduct a JSA during the early stages of the planning process, even before any mobilisation occurs on the construction site. It is during this process that all activities, lay-down areas, equipment locations are planned from a safety perspective. This step has also been described as an important aspect of planning the construction operations during the pre-bid phase of the project by researchers Thomas and Ellis (2007). Some superintendents also identified enforcing company safety rules as one of their responsibilities, which might require them to suspend people from working due to violations. Superintendents described that they were required by their companies to conduct safety checks on equipment. Superintendents also give out hard-hat stickers to construction workers, signifying the level of training completed by the worker.

Construction companies are very proactive about safety training for their workforce and have well-established organisational standards, as shown in Figure 4.5. Several superintendents indicated that their construction company has a dedicated safety department within the company. In addition, several companies have a safety manual that in many cases is more stringent than OSHA’s safety manual. Some companies created a ‘Safety Incentive Program’ wherein a prize was awarded or a bonus was given to workers that exhibited excellent safety practices. Superintendents work closely with the safety officers within the company in developing and implementing a safety plan for the construction site.

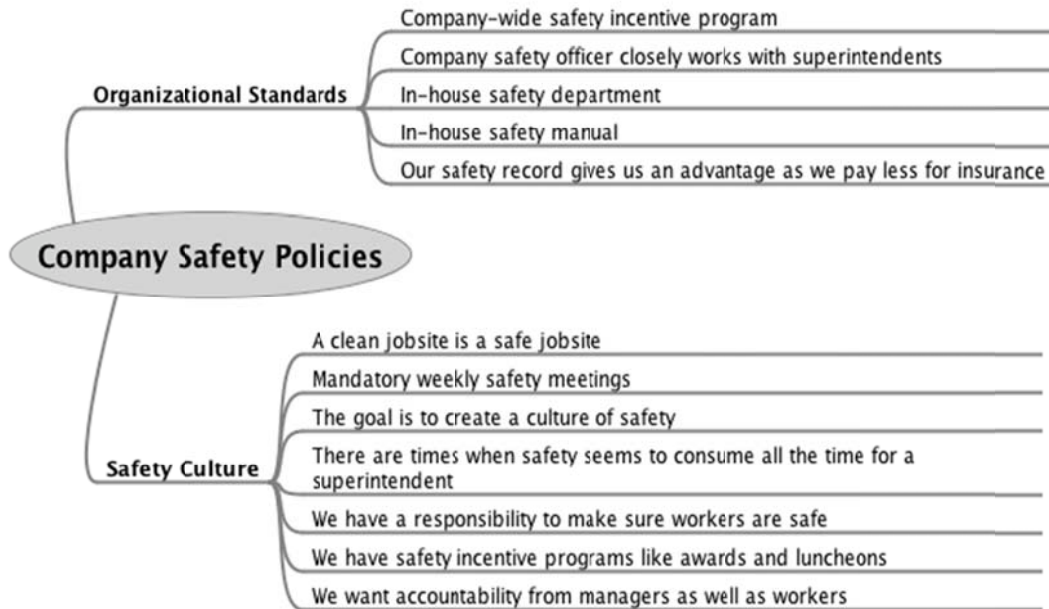


Figure 4.5: Company safety policies regarding ‘Organisational Standards’ and to develop a ‘Safety Culture’

Superintendents spoke about companies wanting to create a culture of safety rather than simply enforcing safety. Companies designated certain days of the week for a mandatory safety meeting for the entire job. There is a stress on maintaining a clean construction site. Several superintendents spoke about the need for personal responsibility from the managers as well as the workers and their own moral responsibility towards the safety of their workers.

From a quantitative content analysis perspective, more than 50 % of the interviewees indicated that companies focused on ‘Continuous Training’, ‘OSHA Certification’, ‘Company Safety Manual’ and ‘Task Specific Training’ as the key items done to maintain health and safety on a construction site. As shown in Table 4.2, more than 25% of the superintendents also commented that ‘Job Specific Safety Plan’, ‘Company Safety Officer’ and ‘OSHA certification’ as important issues regarding safety from the company policy perspective.

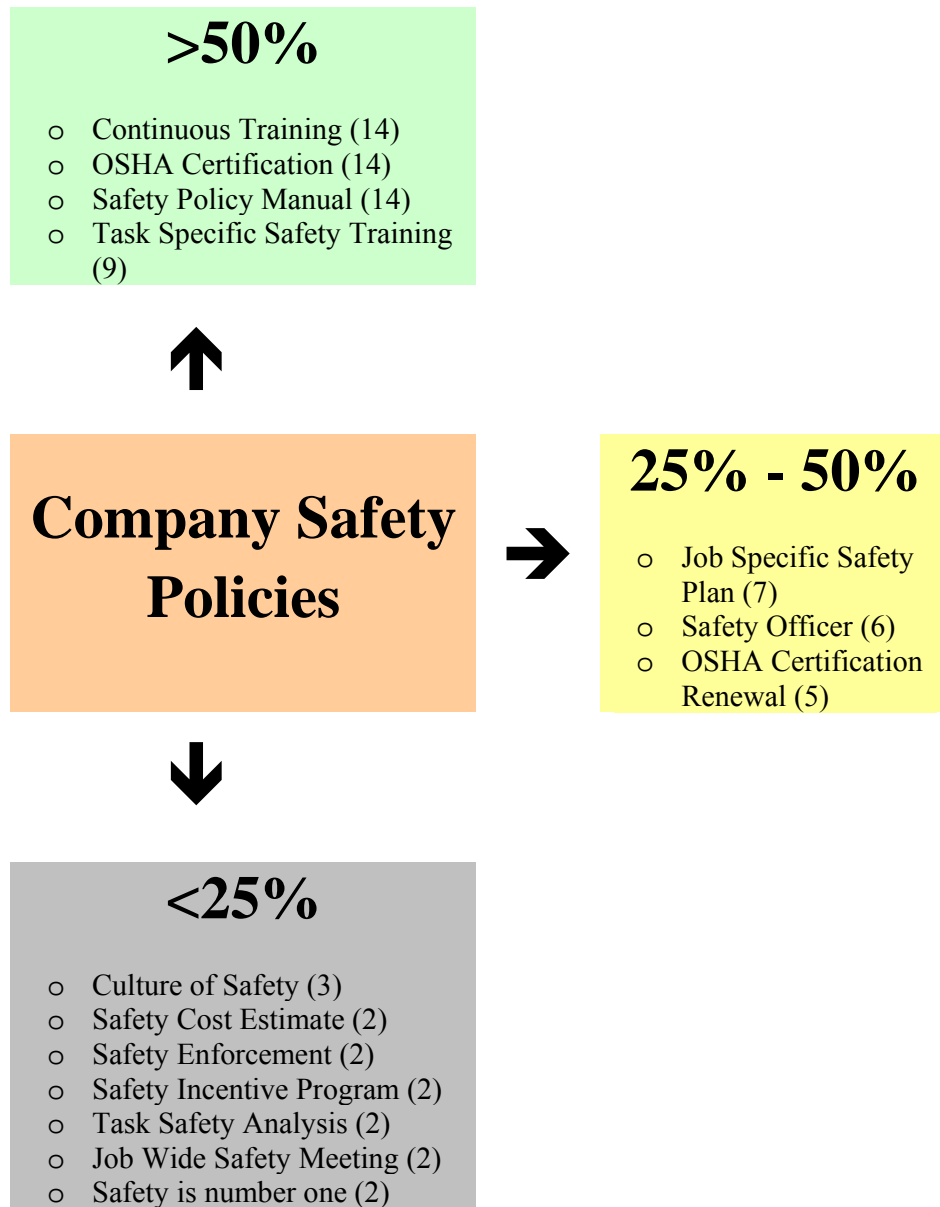


Table 4.2: Superintendents' perspective on Company Safety Policies.

The role superintendents play in ensuring a safe construction site is critical and is well acknowledged (Kines et al., 2010; Chan et al., 2008). Construction supervision was described by one of the interviewees as “*Orchestrating an organized chaos, in the best of times*”. In an effort to understand how superintendents viewed safety, they were asked to describe their personal approach to safety and the various aspects they

consider to ensure a safe construction site. Superintendents presented their own unique approach towards construction site safety. ‘*Safety culture*’, ‘*Safety enforcement*’, ‘*Safety inspection*’, ‘*Safety training*’, ‘*Safety meetings*’ and ‘*Other related issues*’ emerged as the dominant themes for this question, as shown in Figure 4.6.



Figure 4.6: Construction supervision issues for maintaining site health and safety

‘*Safety*’ was at the back of the mind in everything superintendents observed and did on the construction site. The results for this question provided the highest number of codes; however it also resulted in the fewest number of repeated codes. This could be an indication that every superintendent had a unique approach to maintaining health and safety on construction safety. Issues regarding ‘*Safety enforcement*’, ‘*Safety inspection*’ and ‘*Safety training*’ are presented in Figure 4.7. Task hazard analysis is conducted by some companies for each task to ensure that everyone doing the work clearly understood the safety risks of that operation. Superintendents spoke about the use of safety signage and barricades as an important measure of enforcing safety on the construction site. It was important for the superintendent to show the workers that the safety officer was to be taken seriously. On large construction jobs, superintendents used multiple safety officers.

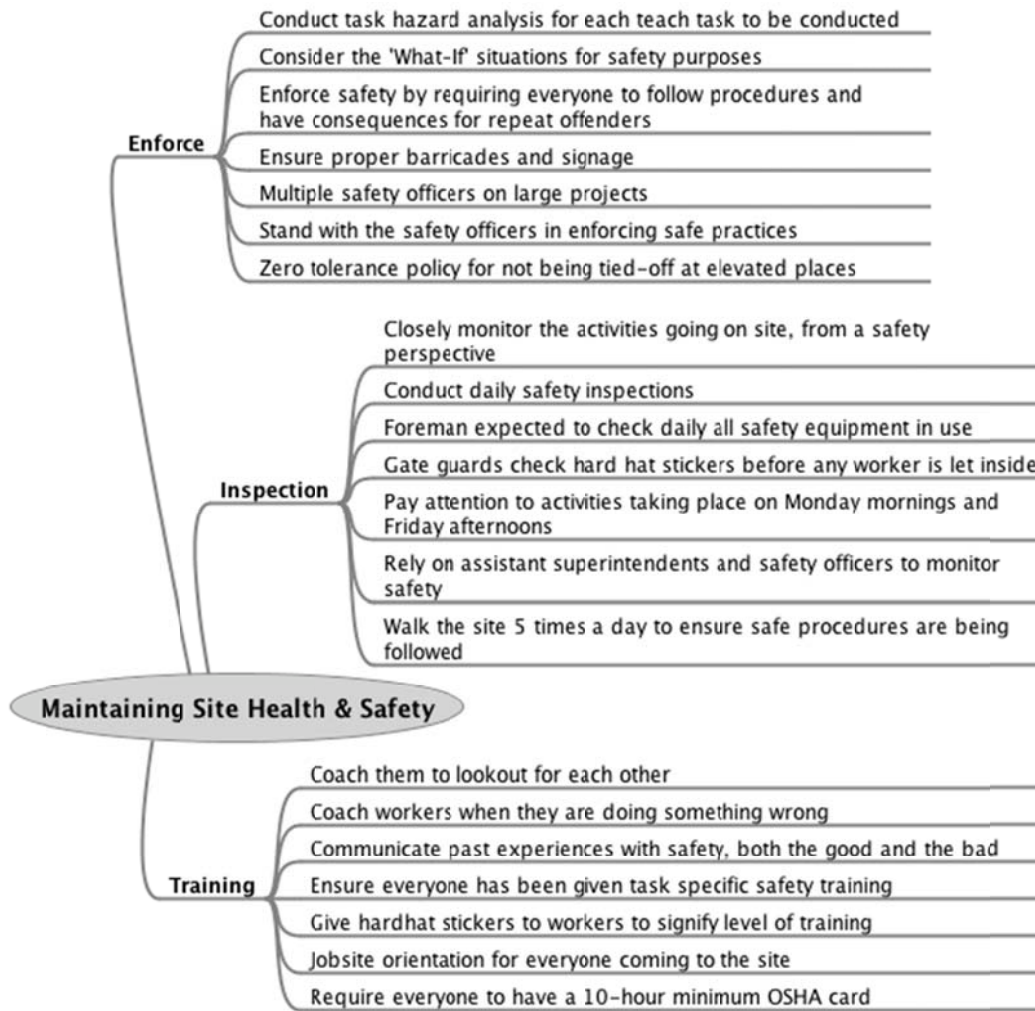


Figure 4.7: Safety enforcement, safety inspections and safety training for maintaining site health and safety

Enforcing safety regulations was seen as an important aspect of safety implementation and some even indicated a ‘zero tolerance policy’ for violators. The example provided by multiple superintendents was the case of ‘Fall Protection’. OSHA requires workers to be tied off or have a fall protection system in places when working at heights. This height varies according to OSHA guidelines, based on the activity, however several interviewees indicated that it was their company policy to have fall protection systems in place when workers were expected to perform over a height of six feet (OSHA, 1996). Superintendents closely and constantly monitor the activities taking place to ensure that they are being safely carried out. Some superintendents require their

foremen to conduct safety inspections on equipment being used and the gate guards check hard-hat stickers to ensure that everyone has the required level of safety training. Superintendents commented about hardhat stickers as a method for keeping up with personnel in various roles within the sites. Sticker colours on the hard hat indicated the role of the worker or in some cases where they were allowed within the site or what type of equipment they were allowed to operate. Superintendents also have to be extra careful when workers may not be fully attentive on Friday afternoons and Monday mornings. Most of these superintendents had grown up through the ranks within the construction industry and several of them spoke about coaching workers when they saw something being done incorrectly and coaching them to look out for each other from a safety perspective. A jobsite orientation is conducted for any new worker entering the construction site. Superintendents also try to ensure that everyone has the proper level of training for performing a task and some superintendents require all workers to have the 10-hour OSHA safety certification.

Developing a safety culture on the construction site, reinforcing the importance of safety during meetings and a few others issues were important for site superintendents to maintain health and safety on a construction site, as shown in Figure 4.8. Some superintendents indicated that the best approach to safety was to create a ‘culture of safety’ on the jobsite as opposed to simply enforcing safety as another rule. Buy-in from construction workers regarding safety is important for superintendents and they try to have informal conversations about safety with the workers. Superintendents remind workers about the dangerous nature of the industry and that each day there are three to four deaths in the United States, related to construction, as evidenced by this quote: *“I tell them that you work in a dangerous environment, that every day on an average people 3 or 4 people die in this industry and I go through and talk about recent incidents around the country. Every one of them could have been preventable. Everyone did it 99% of the time correctly and that 1% when they took a shortcut and they probably did it a 1000 times but this time it caught up with them and that’s just the deaths not everything else.”* Safety is one of the first things they discuss with their subcontractors and several of them commented on setting safety expectations early in the process. Some superintendents conduct weekly or monthly safety meetings that

are mandatory for all workers on the construction site. Safety as a topic is discussed in multiple meetings with the staff, at all levels of the workforce.

Superintendents commented about the importance of a clean jobsite to avoid injuries, which is also reinforced by the study conducted by Mattila et al., (1994). Superintendents spoke about including language about safety in subcontracts, describing safety expectations and safety clauses as well as making sure that enough resources were allocated in the budget to perform the work safely. Not knowing where all the workers are can be a challenging issue for construction superintendents. Construction sites are constantly changing in terms of the activities being performed and the hazards also keep shifting correspondingly.

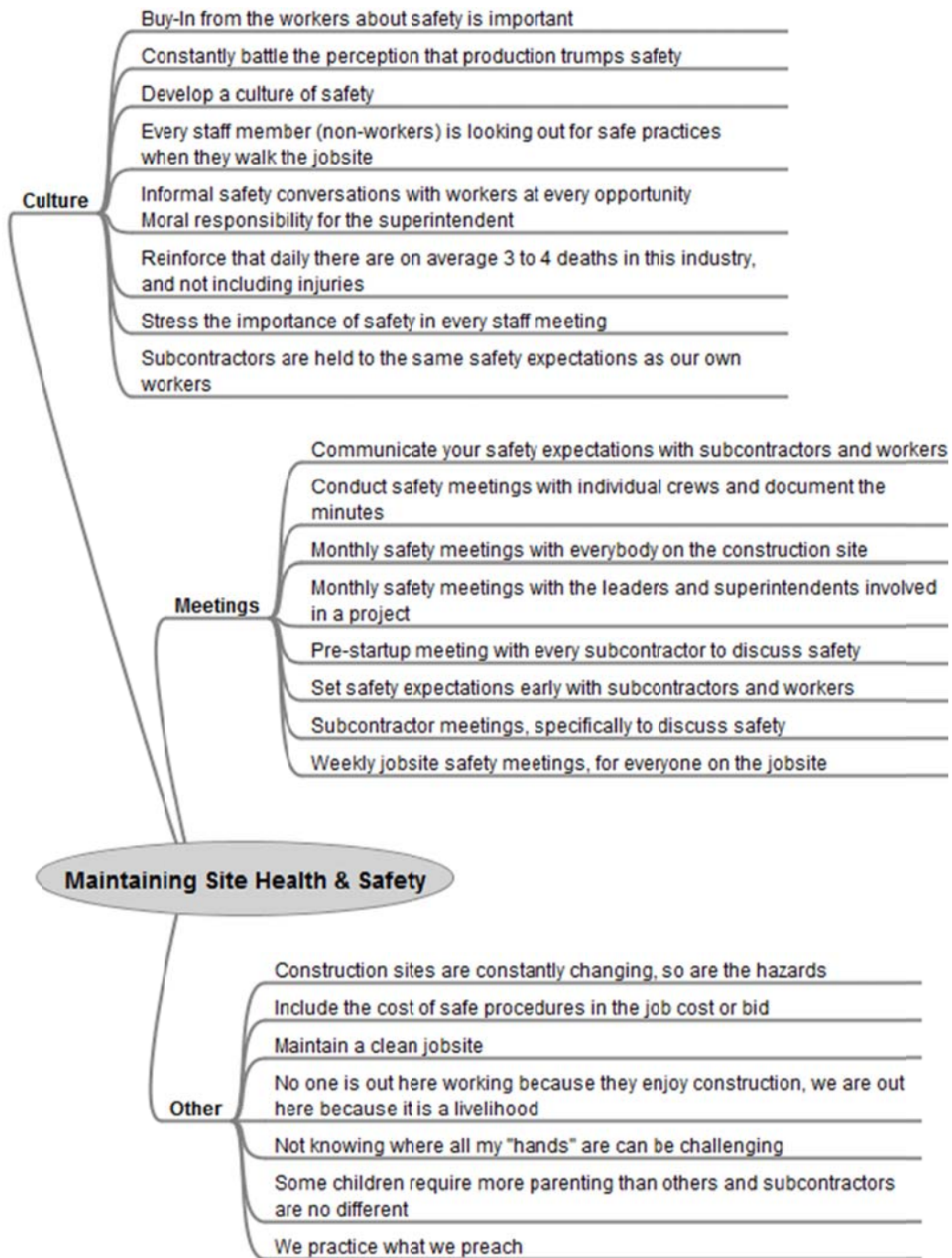


Figure 4.8: Safety culture, safety meetings and other issues to consider to maintain site health and safety

From a quantitative content analysis perspective, 74% of the respondents indicated that they conducted daily safety inspections; some even indicated that they did so multiple times in a day to ensure a safe site, as shown in Table 4.3. More than 25% of them indicated that conducting TSAs, enforcing safety, safety communications, daily safety meetings, developing a culture of safety and weekly safety meetings for everyone on the jobsite. More than 25% of them also mentioned about a job safety orientation for all new personnel on the construction site, before they can do any work. More than 25% of them also identified safety enforcement, conducting task safety analysis, safety communications, weekly / daily safety meetings, safety training and safety coaching as important aspects of their duties towards safety. Superintendents also commented on collaborating with safety officers within the company. More than 25% of them also mentioned that they tried to set safety expectations for their subcontractors, very early in the process and monitor to ensure that they are being observed. Several superintendents commented that safety was not just one of their duties but was also a moral obligation towards all their personnel on the construction site, as evidenced by the quote: *“My number one goal in life has always been, as a superintendent that no one gets seriously injured or killed on a project that I'm managing.”*

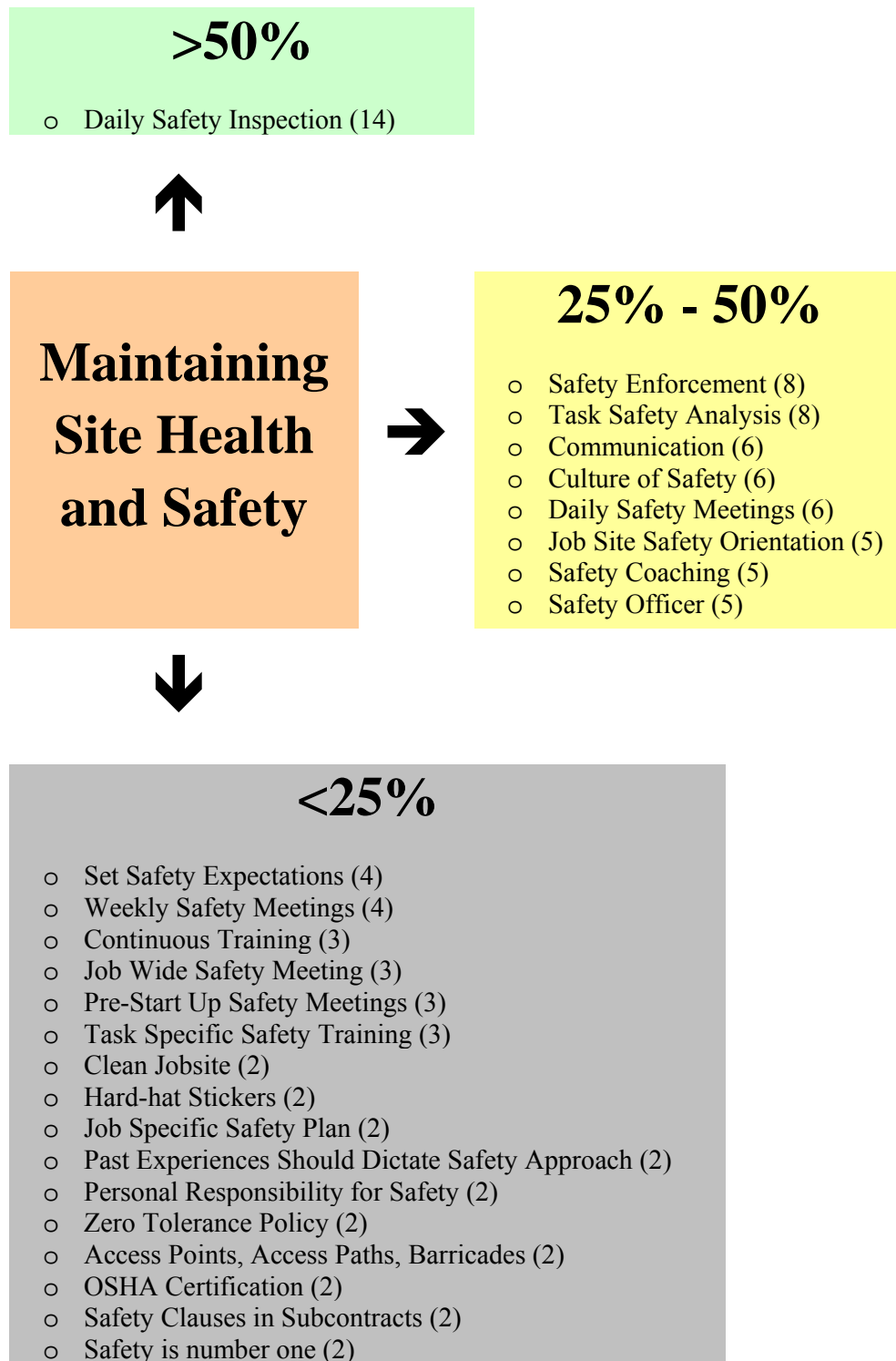


Table 4.3: Superintendents' perspective on maintaining a safe construction site.

4.5.3 Location of Construction Workers on site

Supervision of work under construction in one of the many issues that is part of the site superintendent's responsibilities, as evidenced by the results in section 4.3.1. Safety incidents have been known to occur due to "...*poor attitudes and bad behaviours of the workers which are difficult to monitor and control*" (Teo et al., 2005, p. 331). Even though it is obviously not possible for the superintendent to watch every activity being done by every worker, it is essential that superintendents are constantly monitoring the construction site and the activities taking place. Superintendents were asked about how much time they spent in a typical workday walking and observing the work being performed on the construction site. This question allowed the researcher to understand the amount of time spent by superintendents actually supervising the work under progress within any given day. The results for this question are presented in Figure 4.9 and in Table 4.4.

The results in Figure 4.9 indicate that the amount of time spent by superintendents on the site depended on the activities taking place on the site, size of the project and the stage of the project, but they try to spend at least half the day in the field and walking the site at least three/four times a day, as evidenced by the quote: "*The number of times I walk the site has a lot to do with the size of the job, but you walk the site first thing in the morning, right after break, right after lunch and the end of the day, so at least four times.*" Some interviewees commented about trying to spend at least 25% of their time on the site whereas others mentioned 80% or more of their time walking the construction site. Superintendents commented about walking the site at critical times during the day but mostly in the morning, afternoon and after everyone had left the site in the evening as evidenced by the quote: "*At a minimum we try to walk the jobsite in the morning, at noon and again late afternoon, so we can see how everybody is getting started out, at lunchtime to see how they are progressing and in the afternoon, to see how far they got done.*" Some superintendents commented on being on site when hazardous activities were taking place. On large construction sites some of them depended on area superintendents to handle the work in different areas of the construction site.

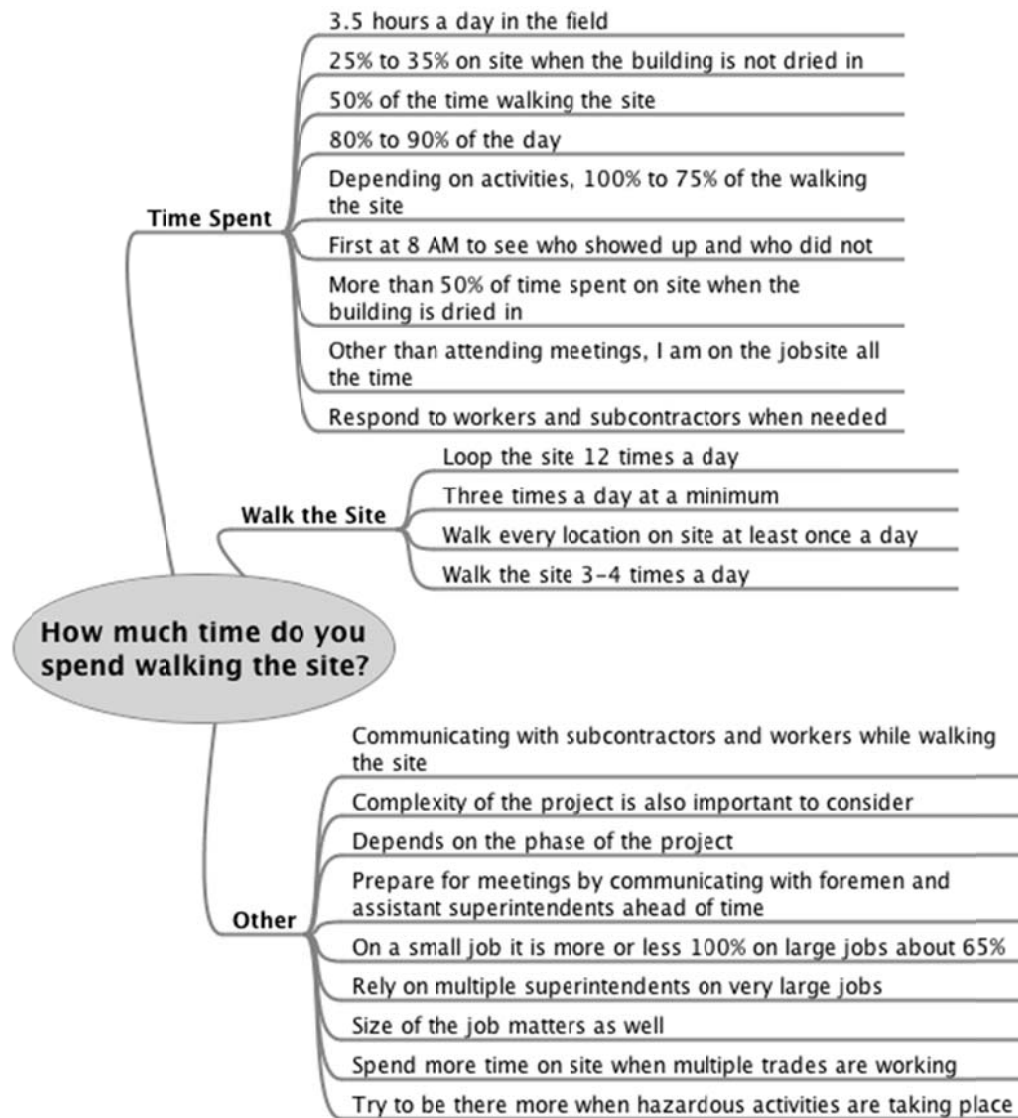


Figure 4.9: Time spent by superintendents walking the construction site to monitor activities taking place

More than 50% of the interviewees indicated that they spend 40-50 % of their time on the site, walking the site from 3-5 times in a day, as shown in Table 4.4. More than 25% of them also commented about spending more than 60% of time on the site and more than 25% of the interviewees also indicated that they depend on area superintendents on large jobs. More than 21% of them also commented about walking the site to conduct daily safety inspections.

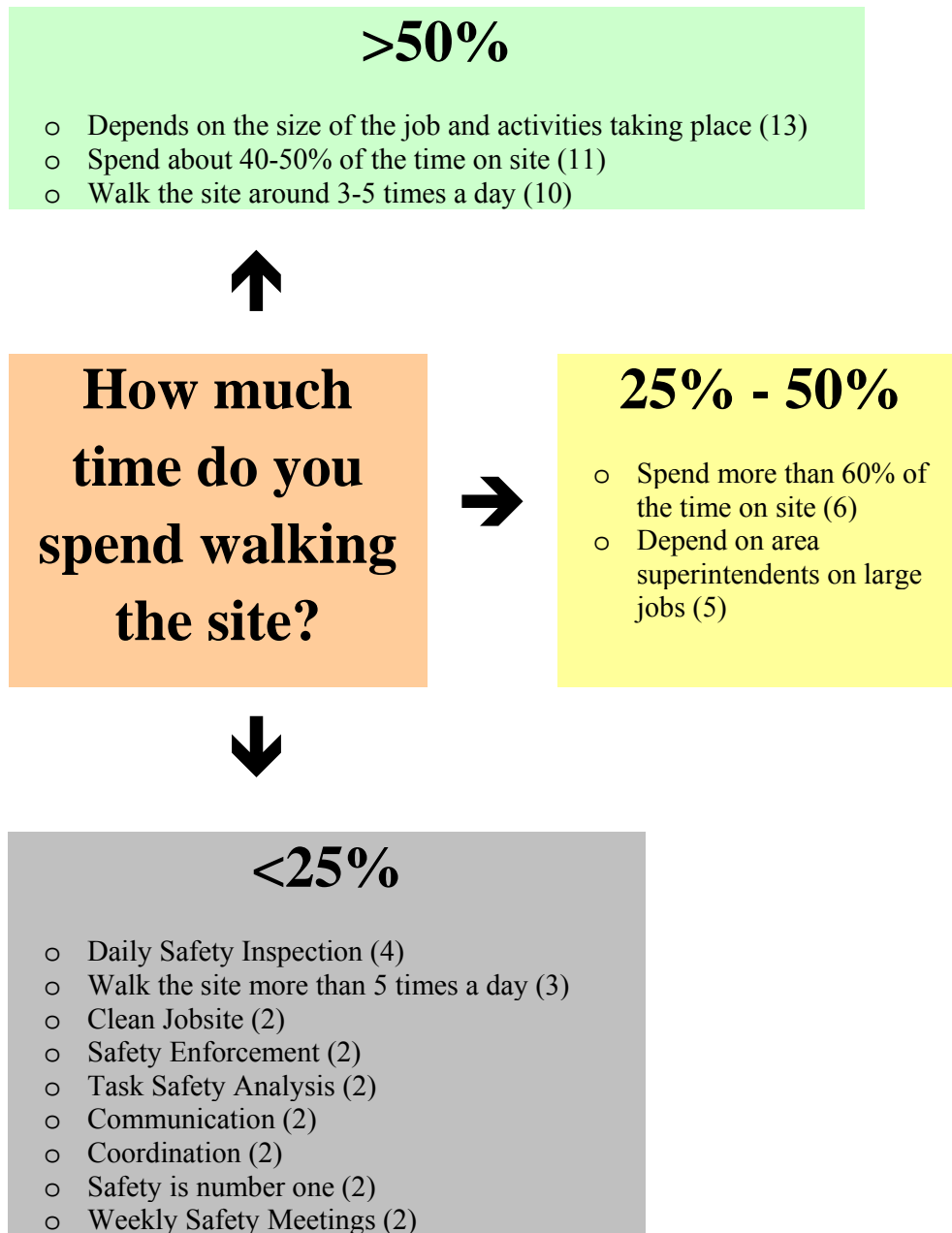


Table 4.4: Superintendents' perspective on time spent walking the construction site.

In order to further understand the issue of monitoring, the participants were asked about how they knew the location of people working on their construction site. Research has shown that when workers are visibly monitored by their superintendents

it provides for more dialogue between the worker and the superintendent and that it has a direct positive impact on safety (Luria et al., 2008). Therefore, this question established the basis for a need to create an automated location tracking system to monitor the movement of workers by the superintendent. The results to this question are presented in Figure 4.10 and in Table 4.5.

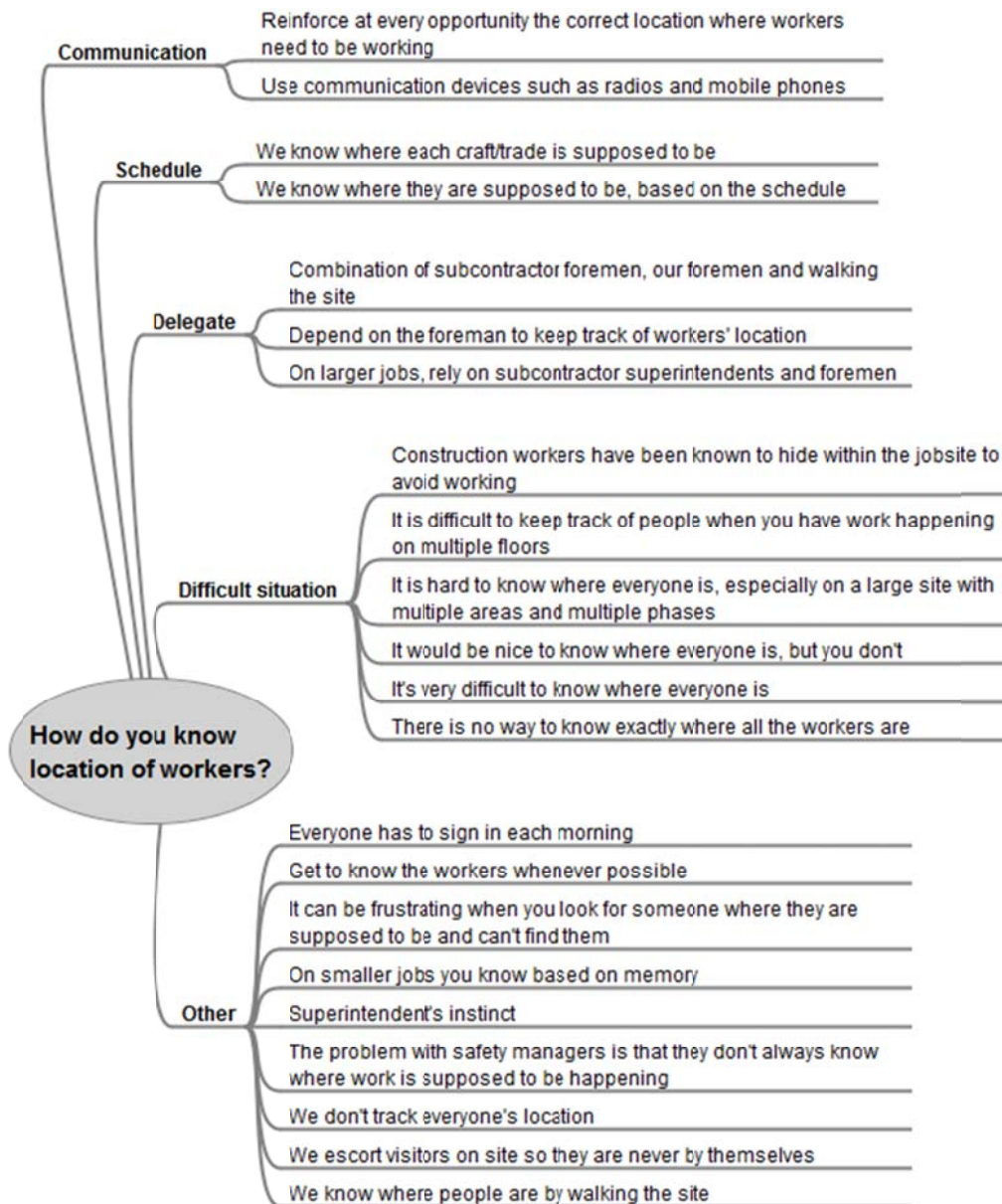


Figure 4.10: Superintendents' knowledge of location of construction workers within the construction site

Superintendents use communication devices such as radios and mobile phones to know where workers are located and stress the importance of working in designated areas only, with the workers, as shown in Figure 4.10. Superintendents use the schedule to understand where the workers or various trades are expected to be working as evidenced by the quote: *“We know where they should be based on the activities that are going on that day and also as we walk through the site.”* Foremen for crews, subcontractor superintendents and area superintendents on larger jobs are expected to keep with worker locations on a construction site. Workers are expected to sign-in when they arrive on site and some superintendents escort all visitors to the construction site. Using safety officers can be useful but safety officers do not always know where the workers are supposed to be working. One interesting aspect they seemed to suggest was the ‘Superintendent’s Instinct’, which was phrased in several ways but amounted to developing an instinct based on their experiences in previous construction jobs, as evidenced by the quote: *“Well, one thing, a lot of older guys like myself, we probably work from a feel or an instinct and we know where they are supposed to be. Of course I know schedule as well so I know what work is going on.”* It is a difficult scenario for construction superintendents, as they do not know where everyone is working at any particular time, without them having to go and physically inspect areas of the site.

89% of the superintendents said that they knew where people were supposed to be working based on what activities they were performing, as shown in Table 4.5. More than 50% of them walked the site to monitor progress of the work and to know workers location. More than 50% of them also said that it is impossible to know everyone’s exact location at all times on the jobsite. More than 25% of them mentioned that the foreman and subcontractors were expected to know where everyone they were overseeing is at all times on the jobsite and more than 25% of them indicated the use of communication devices to know where work is taking place.

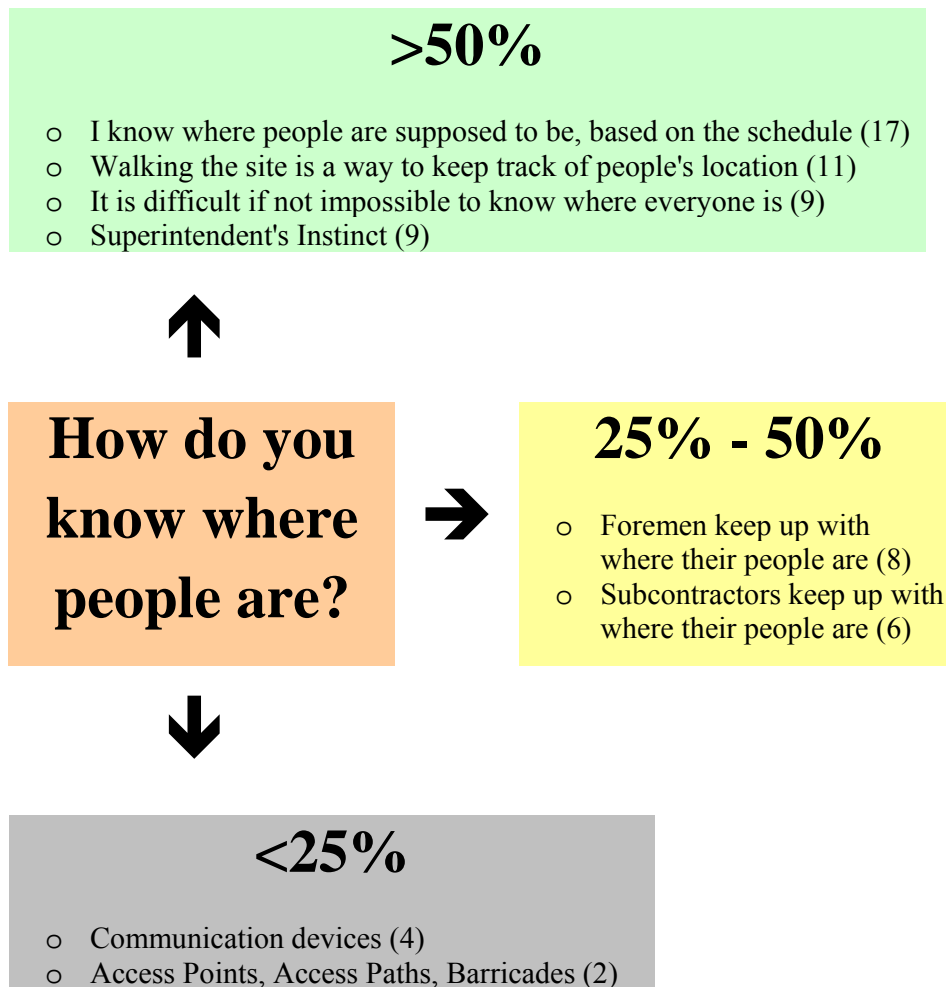


Table 4.5: Superintendents' perspective on location of people within the construction site.

Further probing the location of site workers, superintendents were asked if it was important that they knew everyone's location and how they would use this information. This question revealed how the superintendents used the location of people on the site to monitor various aspects under their purview. The results to this question are presented in Figure 4.11 and Table 4.6. The results reveal that superintendents consider knowing workers' location important for multiple reasons. Knowing workers' location is useful from a production standpoint, coordination between trades' standpoint and from a quality inspection standpoint. Another important factor for the superintendent to know the location of workers is due to

safety concerns. Knowing workers location can be useful during emergency evacuations, on large jobsites, when hazardous activities are taking place, on congested sites and when certain barricades and signage posts have to be moved, thus creating a safety hazard. During an emergency evacuation, it may be that the missing person could be injured and needs immediate medical attention as evidenced by the quote: *“Yes it is very important to know. There is a lot of high-tech equipment on site and if a safety incident were to occur, I would like to know where everybody is at, in case I have to evacuate the site”*. Superintendents once again mentioned that it is very difficult if not impossible to know where everyone is located on a construction site, especially on larger construction sites and that it is very difficult to know every worker personally. Superintendents also reiterated that the foremen and trade contractor superintendents should know the location of their crew on the construction site.

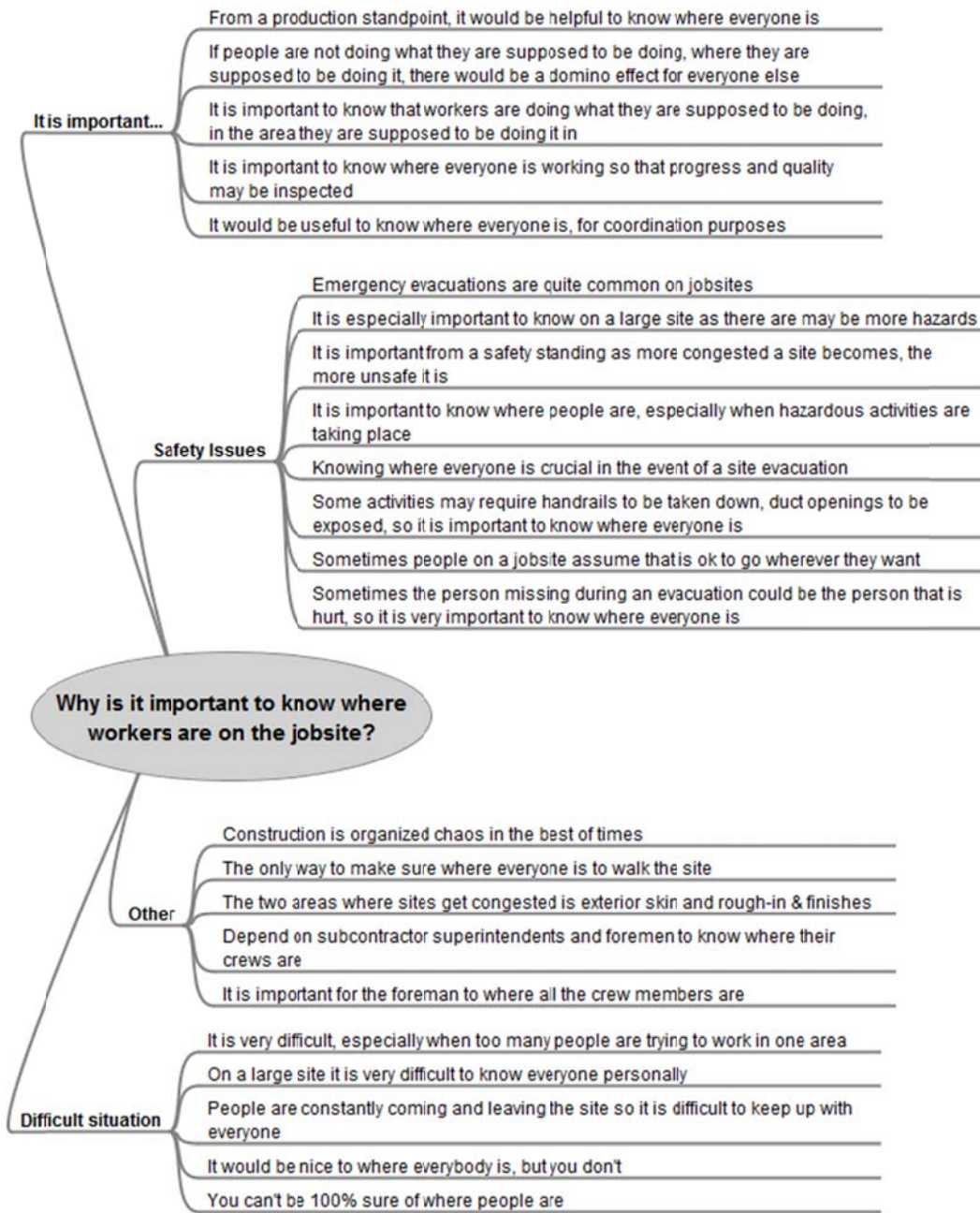


Figure 4.11: Importance for construction superintendents to know location of workers within the construction site

The results for this question evaluated using quantitative content analysis methods are presented in Table 4.6. More than 50% of the interviewees agreed that it is important to know where everyone is so they could monitor the progress of the activities taking

place on site and 95% agreed that it is important for the superintendent to know location of workers within the site. More than 25% of the superintendents commented that it is important to know workers' location for issues regarding coordination as barricades that might have been moved, during emergency situations and due to the fact that the hazards on a construction site are constantly changing. More than 25% of them also commented that foremen must know the location of workers that barricades might be moved due to certain activities, and that is very difficult to know the location of workers on site.

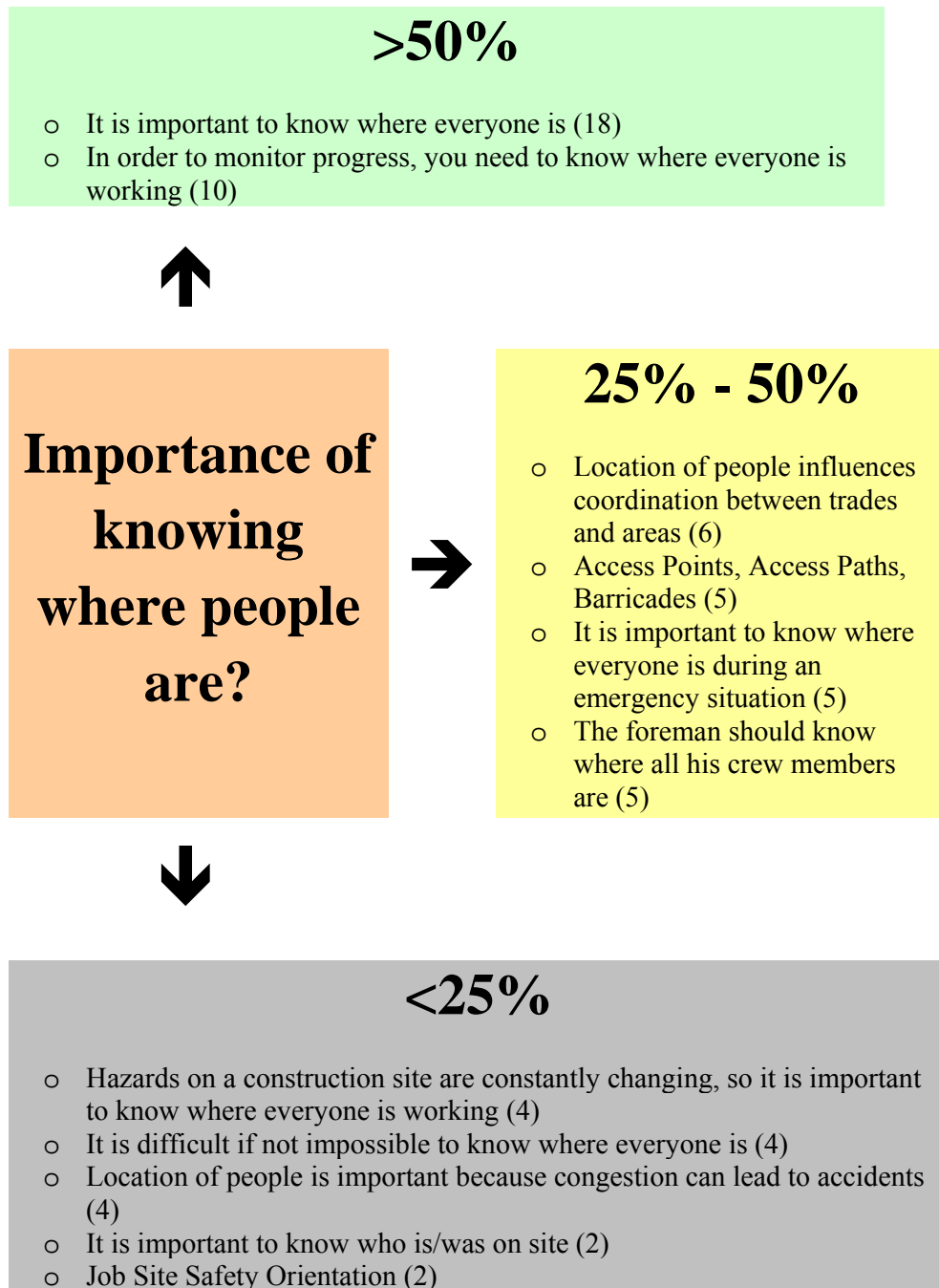


Table 4.6: Importance of knowing the location of people within the construction site

Responses to previous questions have indicated that congested construction sites can cause accidents. Vision based tracking methods have been suggested to track workers

on congested construction sites (Brilakis et al., 2011). However, this technology would be ineffective in identifying individual workers or tracking personnel working inside buildings (Yang et al., 2010). Therefore participants were asked if there were ever instances when there were too many people on the construction site and if this poses any managerial problems in and of itself. This question allowed the researcher to further probe the importance of workers' location information to the construction superintendent. The results to this question are presented in Figure 4.12 and Table 4.7.

Superintendents indicated that there are many occasions when there are too many people on the construction site. Common situations when this happens include large jobsites, on multi-storied structures and when tight schedules require multiple crews in the same location. From a safety perspective this becomes an issue when hazardous activities are taking place on site and when working on occupied buildings, where it can be very easy for the occupants of the building to walk into an unsafe area of the site. Superintendents invariably have to rely on more personnel to monitor the construction site to ensure safety and they do so by adding on area superintendents or by relying on foremen to know all the people working in their area. There were some comments made again about not being able to keep up with where everyone is located within the site. Incidents about strangers with a hard hat walking into the site and the challenges it presented were reported. The issue of congestion again seemed like a particular concern as evidenced by the quote: *“When we get into logjams is when we get behind on the schedule, when there are too many people trying to work in one area. It is possible to put two people on something and get it done quicker than putting 10 people to do the same thing.”*

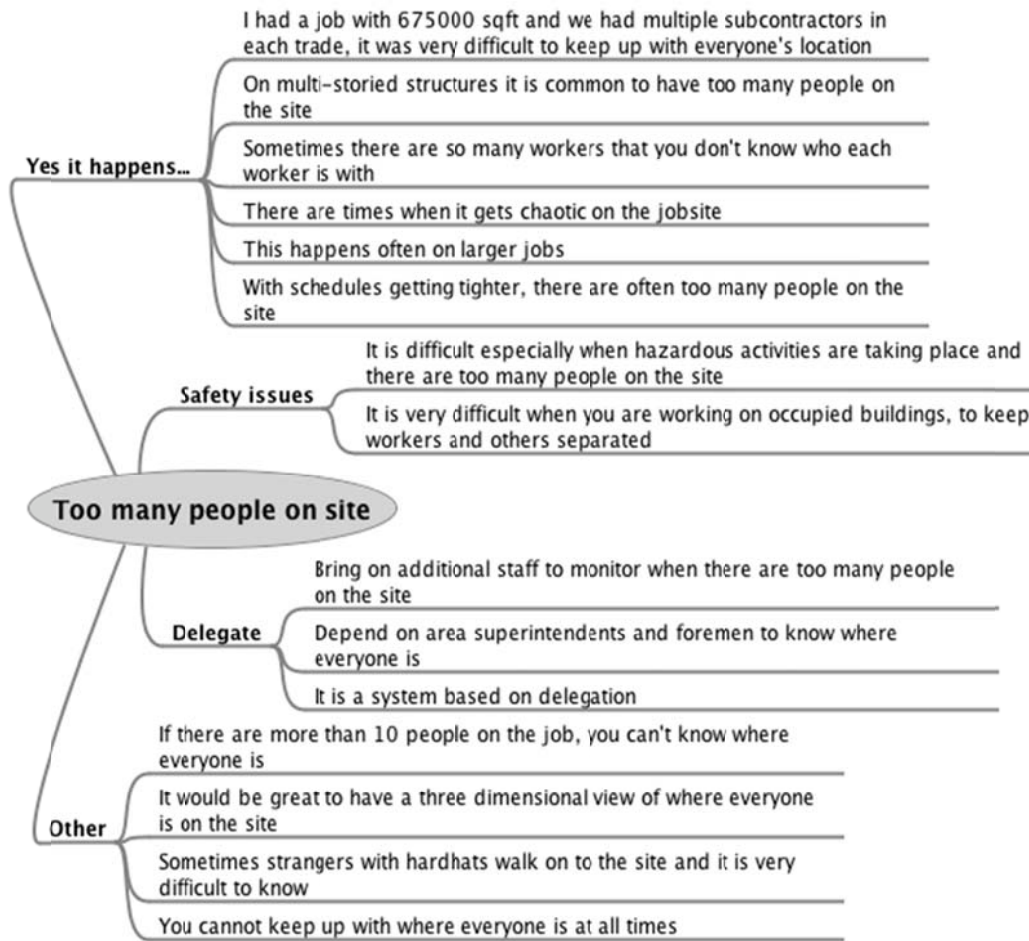


Figure 4.12: Superintendents' perspective on crowded construction sites

Seventeen of the nineteen interviewees agreed that there are often situations when there are too many people for one superintendent to monitor effectively. Under those circumstances, 79% of the interviewees mentioned that they bring in additional personnel such as area superintendents and assistant superintendents to help monitor the construction activities on site. More than 25% of the interviewees commented on relying on foremen and subcontractor superintendents to keep up with their personnel.

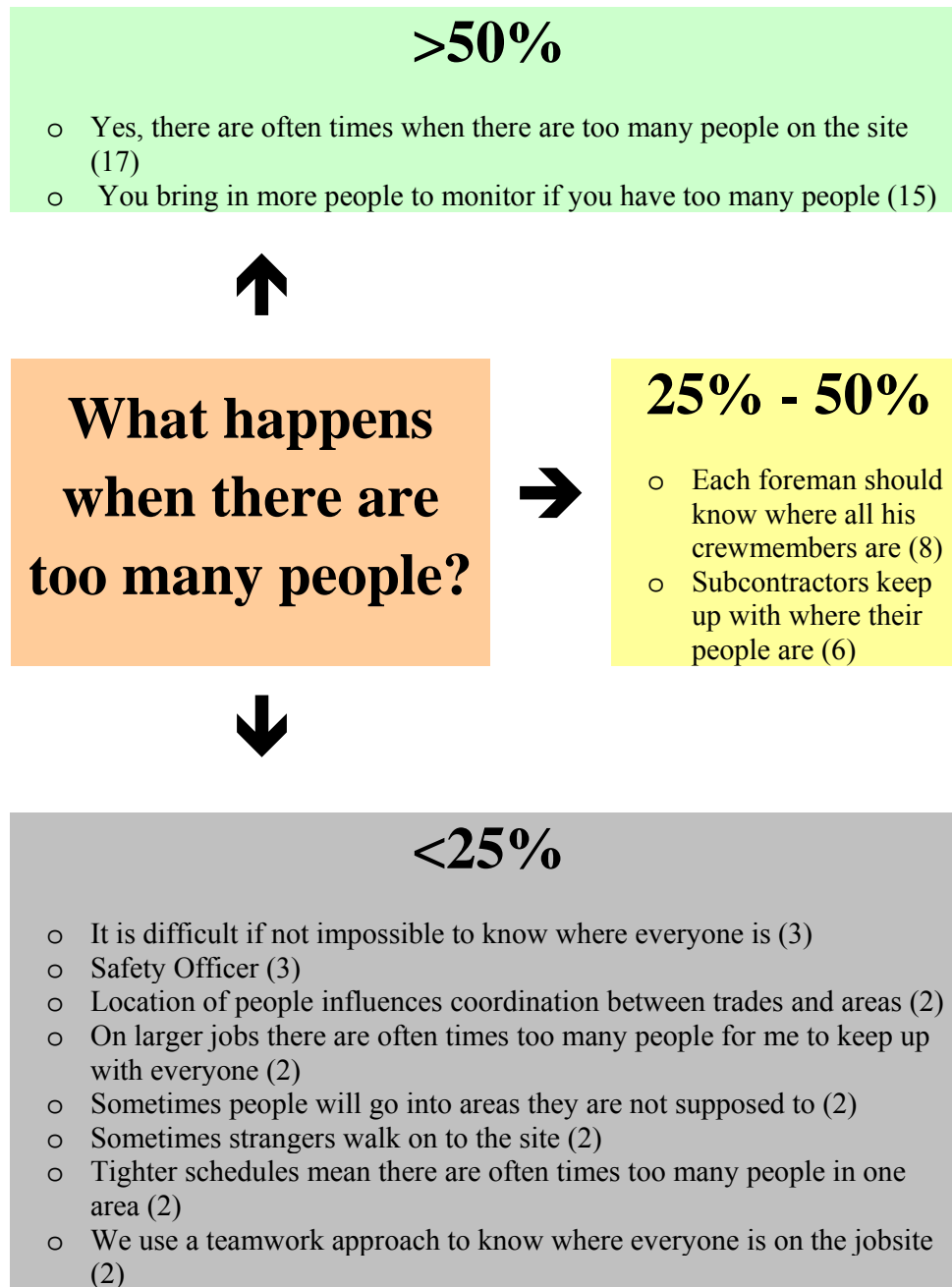


Table 4.7: Superintendents' perspective on crowded construction sites.

4.5.4 Safety Incident History and Accident Prevention

A 'Near Miss' accident can be defined as an accident that could have occurred under slightly modified conditions (Phimister, et al., 2004). The use of 'near miss' accidents

to prevent actual accidents is on the rise in the construction industry (Wu et al., 2010). It stands to reason that when a superintendent experiences an accident on the site or witnesses a near miss accident, they would take extra precaution in a similar situation in the future. Superintendents were asked if they were ever in a situation when an accident occurred but could have been prevented if they were physically present at the location of the accident. The responses to this question helped to establish the severity of not knowing people's location, thus leading to unsafe conditions within the construction site. The results to this question are presented in Table 4.8. In addition to the tabulated results based on coding the interviews, specific situations where superintendents gave examples of past accidents that occurred are also presented. Almost half of the respondents said that they had prevented near miss accidents from happening. Some superintendents admitted that safety incidents could occur as a result of people being in the wrong place. However, the superintendents said that most accidents happen when people take shortcuts in performing their jobs.

Have you witnessed safety incidents or near misses on a construction site?



- I have prevented potential incidents by sheer chance because I was there (8)
- I have not seen safety incidents but have seen near misses because people end up in places they should not be in (6)
- Safety incidents can occur because people are in the wrong place (5)
- Safety Enforcement (3)
- Access Points, Access Paths, Barricades (2)
- Culture of Safety (2)

Table 4.8: Superintendents' perspective on construction safety incidents.

Superintendents gave examples of safety incidents that occurred because people were in a location where they were not supposed to be. Superintendents spoke about near

miss accidents, about creating a culture of safety and how they regularly prevent accidents from occurring, as evidenced by the quote: *“Absolutely, almost on a daily basis I see near miss accidents and I prevent them. I think all accidents are preventable. It’s really a mind-set to do everything safely, my approach with all my employees, instead of hound dog them with rules or discipline them, and sometimes discipline is what it takes, but I try to get them to participate to be a team player and teach them to do it safely the first time.”* Superintendents spoke about accidents like a worker falling through an opening and injuring himself because he did not heed a call to evacuate the site due to high wind conditions, example of a clean-up worker getting injured due to falling debris, a worker losing his arm because he ventured into an area where an unexpected steel sheet fell from above him, of a worker killed because he ventured into an area when steel was being erected and one of the connections failed and a steel beam fell on the worker, of a project manager who was killed by a truck that backed over him when he was not supposed to be in that area in the first place and of an equipment operator that got electrocuted because he went to an area he was not supposed to and ran into a live wire with the boom of his equipment. All of these accidents are potentially preventable if a system was available to alert the superintendent or even the worker himself of their precipitous location in a hazardous area.

Certain activities are considered more hazardous than others in construction. Superintendents were asked about how they prepare to undertake activities they deem to be more hazardous, such as a critical lift. It has been shown that the superintendent’s role is essential in maintaining a safe work site with potentially hazardous equipment such as tower cranes(Shapira and Simcha, 2009). This question was asked to establish the need for knowing people’s location during these hazardous activities. The results for this question are presented in Figure 4.13 and in Table 4.9.

Superintendents plan ahead for hazardous activities and communicate to everyone on site ahead of time about the procedures that are expected to take place and think about what-if situations such as inclement weather or high winds for crane lifts. Superintendents use safety checklists and multiple walk-throughs to prepare for

hazardous activities. Communicating to everyone about the activities that are expected to take place emerged as an important aspect of preparing for hazardous activities, as evidenced by the quote *“Of course we use barriers where it is applicable but we try to plan ahead. We try to communicate to people to where work is going on and where they are and where they are not supposed to be. If we find people in areas where they are not supposed to be, we go from enforcement to a disciplinary situation. Because you can’t just wait for people to get hurt and try to take care of them then.”* “All subcontractors and trade workers are coordinated ahead of time to ensure that everyone knows areas within the site where work is being conducted, as well as forbidden areas. Superintendents visually monitor the hazardous work that is taking place and are fully involved in overseeing those activities. Safety monitors are used during hazardous activities, such as critical lifts. Superintendents use barricades and tapes to control designate work areas and use check-in and check-out procedures for workers as evidenced by the quote: *“First thing we do is a visual barricade, like fencing, control access points, flagmen and security guards.”* Only qualified personnel are allowed to work on hazardous activities and disciplinary actions are taken against workers that do not obey safety directives. Superintendents depend on personal accountability from workers to safely perform hazardous activities. Once again superintendents acknowledged that there was no fool proof method to make sure that workers stayed out of hazardous areas.

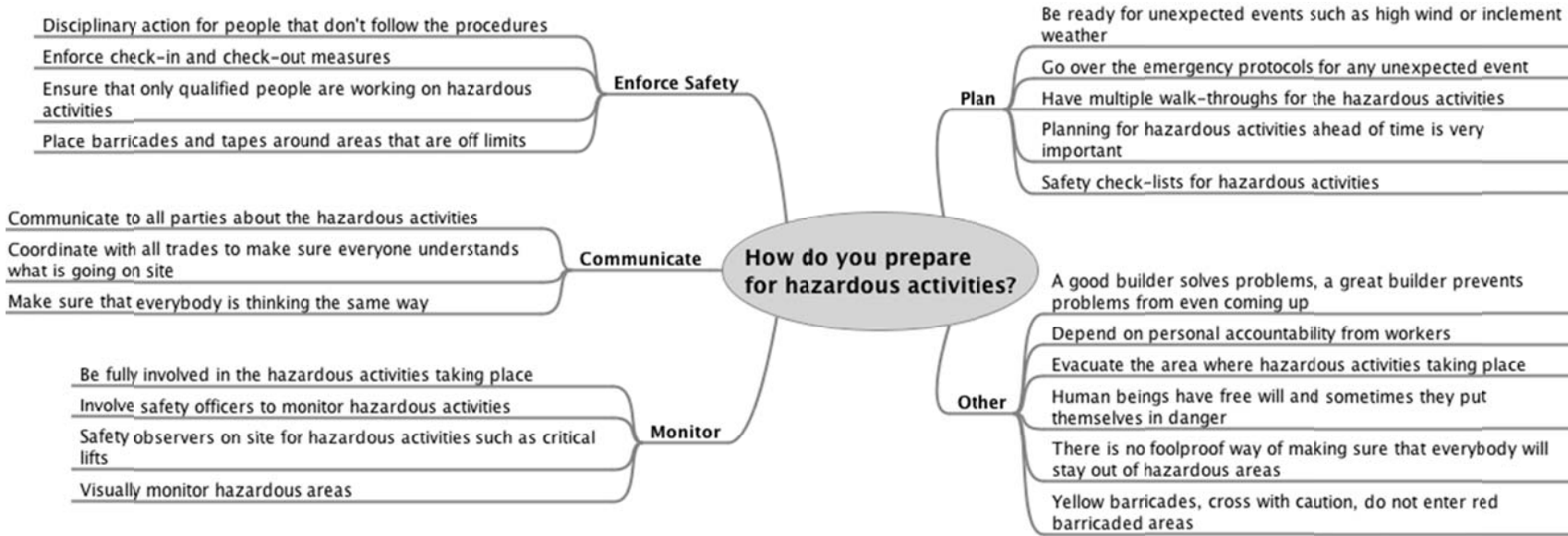


Figure 4.13: Preparing to conduct hazardous activities on a construction site

Quantitative content analysis of interview data revealed that more than 50% of the superintendents cited the use of a safety officer, communication with all parties, safety barricades and safety planning as important issues to consider for performing hazardous activities, as shown in Table 4.9. More than 25% of the interviewees also cited safety checklists and proper signage on the construction site to prepare for hazardous activities.

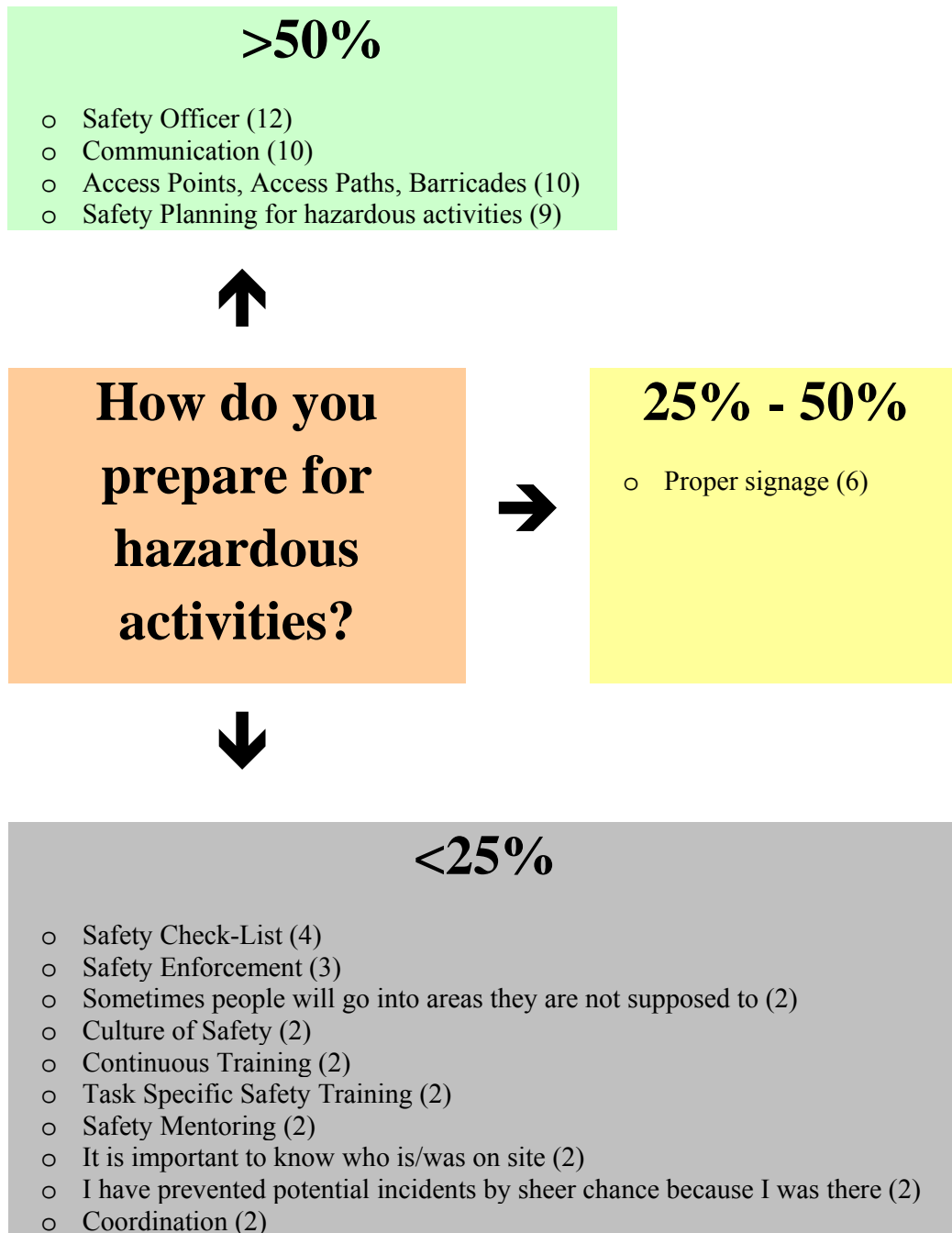


Table 4.9: Superintendents' perspective on preparing for hazardous activities.

4.5.5 Superintendents' Perspective of RFID and BIM Solution

Each interviewee was shown sample screen shots of the proposed solution to combine RFID and BIM to monitor the movement of people within the construction site, as shown in Appendix 4.2. The participants were asked if they would use the proposed system and how it might assist them in performing their roles better. The results for this question are presented in figures 4.14, 4.15 and Table 4.10.

Superintendents agreed that it would be a useful tool and could be used by all superintendents, especially on a large construction site and again mentioned the need to know where people are located within the construction site, as evidenced by the quote: *“That could be beneficial, most especially on a larger job.”* Safety officers could use the proposed tool and it would also save time in allowing the superintendent to have an oversight of workers on the jobsite, without having to walk the entire site. Superintendents mentioned that workers tend to have a ‘macho’ attitude bordering on over-confidence in the construction industry and would be more careful knowing that someone is watching their location. Superintendents mentioned that the proposed solution would be an extension of the pictorial views extracted from BIM models, currently used to assess safety issues. Superintendents cautioned that while the solution may show the location of workers, it should not be used as a substitute to monitor people, as the tool does not show what the workers are doing but only shows where they are. Superintendents also mentioned that the proposed tool must be economically viable for it to be used in construction sites.

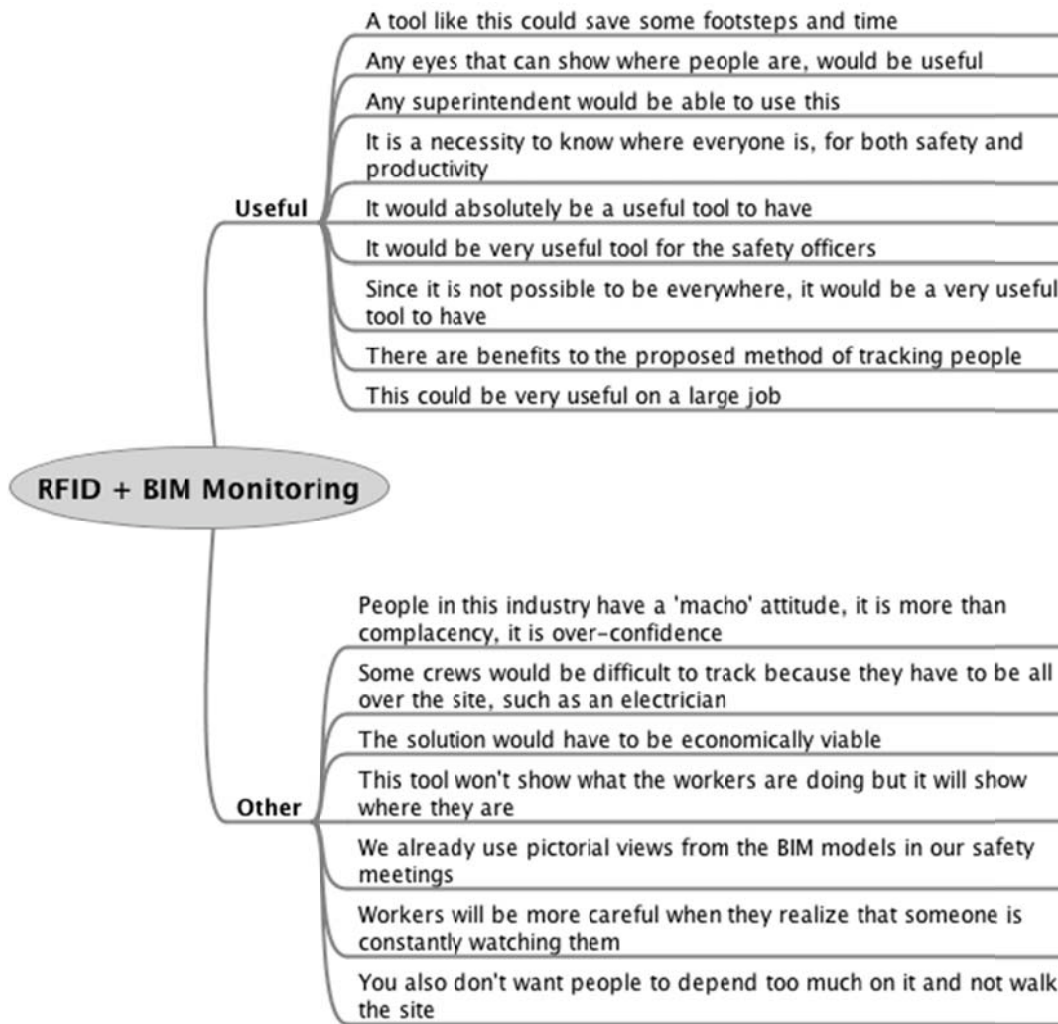


Figure 4.14: Superintendent perspective on implementing RFID +BIM Monitoring on the construction site

Superintendents gave specific scenarios that they thought a proposed solution could be used in the construction industry, as shown in Figure 4.15. Superintendents suggested that the proposed solution would be useful if the various crews were colour-coded, based on their role as shown by one superintendents' quote: *"I believe this could be useful. Especially for specific superintendents too, if you could colour code your people, and watch all of your areas simultaneously to see where people are, yeah I could see that being useful."* Superintendents suggested that it would be a good way to keep up with the location of a crew, to track it against the schedule to

ensure that the crew is producing at the planned rate. Tracking crews by colour coding by role will also ensure that each crew is sufficiently staffed. It was also suggested that the construction site be divided into pre-determined zones and show workers when they enter unauthorized zones. It was suggested that it would be good to highlight the foreman for each crew, allowing the superintendent to identify situations when the foreman is not in the same location as that particular crew. It was suggested that instead of constantly viewing a screen to monitor workers, it would be better to highlight workers that are in the wrong area and an alarm could be used to alert people when they enter an unauthorized or hazardous area. Superintendents saw the benefit of the tool when hazardous activities are taking place on site as well as during emergency evacuations. It was suggested that it could be a useful tool to automate the headcount process during an emergency evacuation. It would be a useful tool to monitor workers throughout the day and to know when people are on site and miss important safety meetings. Superintendents suggested that it could be useful to remotely monitor the site, when they are unable to physically be on the construction site and can be similarly used by the home office to know areas where work is taking place.

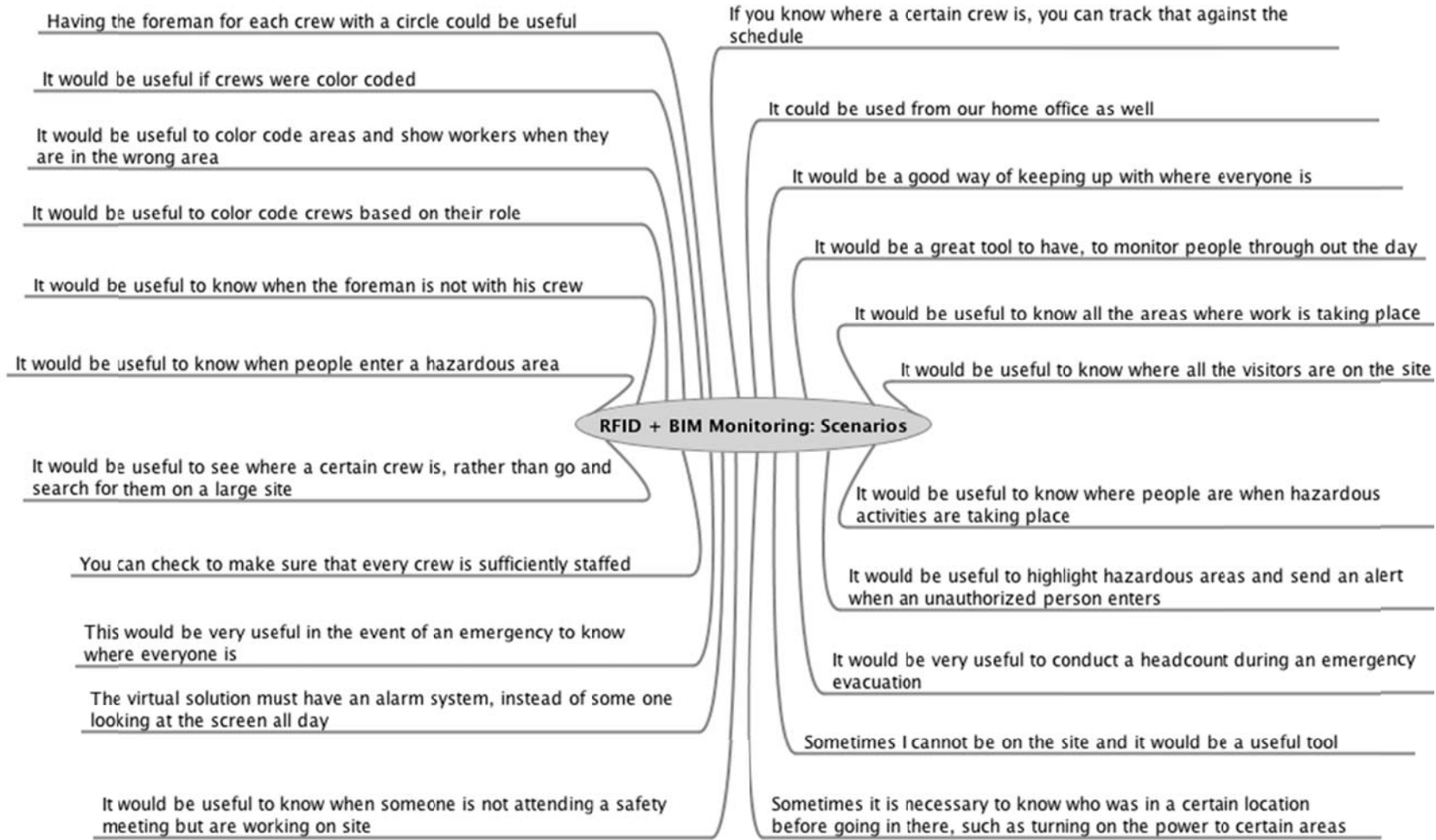


Figure 4.15: Superintendents’ perspective on scenarios where RFID + BIM monitoring can be useful on the construction jobsite

Quantitative content analysis of the data revealed that 95% of the superintendents agreed that the proposed solution would be useful. More than half of them also said that it could be used to monitor the production of construction on site. More than 25% of the respondents mentioned that the proposed tool could be useful if crews were colour coded, on large construction sites, to divide the site into zones and alert people when they enter unauthorized zones. More than 25% of the participants also cautioned that the proposed solution would show where workers are, but would not show what they are doing.

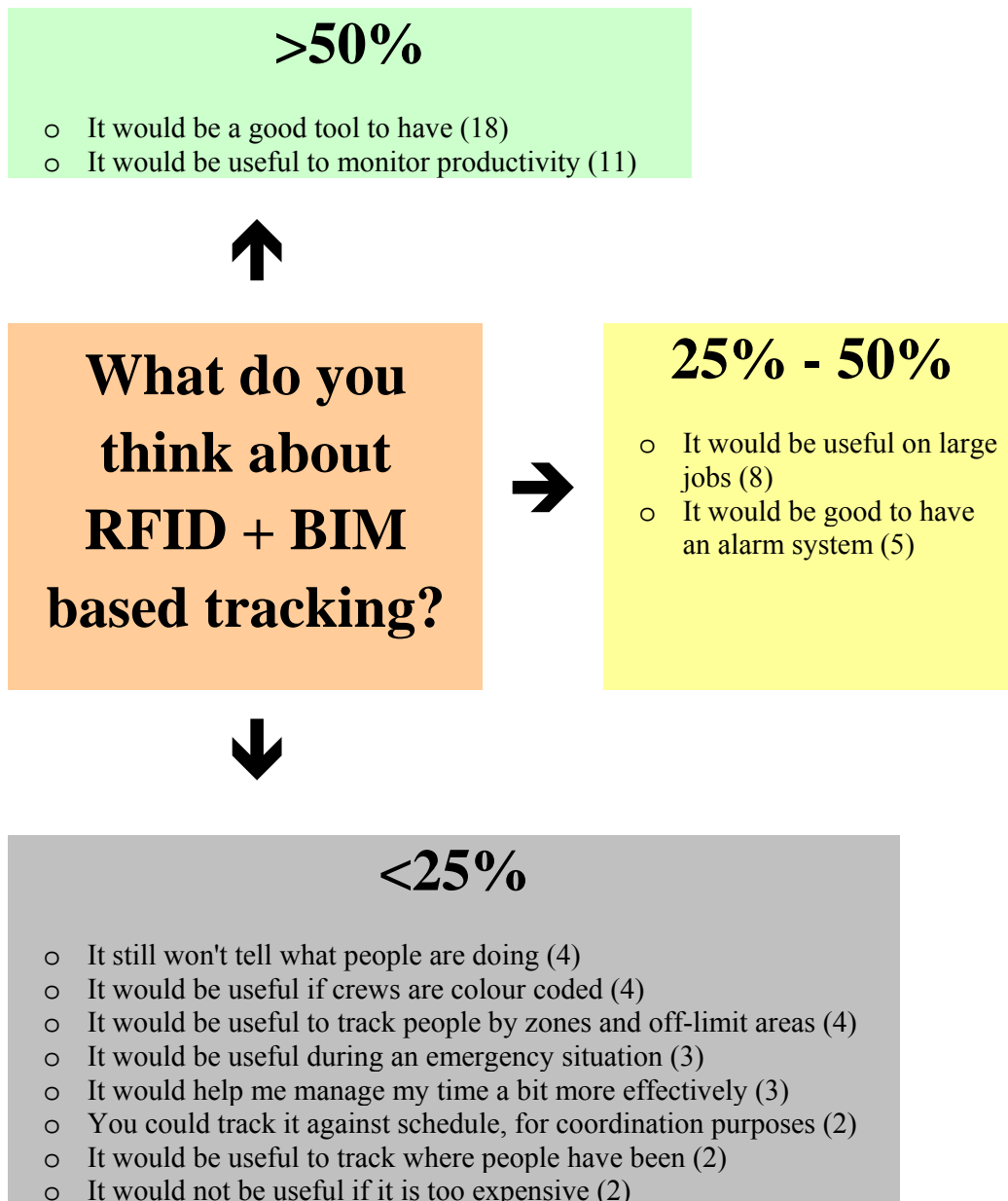


Table 4.10: Superintendents' perspective on location of people within the construction site.

4.6 Construction Supervision

The data collected from the interviews provided a comprehensive understanding of the role of the site superintendent and the various issues they are responsible for. By analysing the data for all questions, the site superintendent's responsibilities are shown in

Figure 4.16. These responsibilities are not independent or mutually exclusive of one another, in fact, more often than not, are dependent on one another. For example, a poorly coordinated schedule may make the site more congested, potentially create an unclean site, is likely to cause delays, increase the potential for accidents and generally resulting in a problematic construction project. Material delivery and storage for example can influence the success of the project as it is the superintendent's responsibility to make sure that materials are approved by the design team, are delivered to the site at a time that does not cause disruption to the public or the workers on site, that they can be moved into place when they are ready to be installed and the equipment necessary to install them is available to complete the work. Mismanaging any one of those tasks can have a domino effect resulting in delays and cost overruns. Therefore, when a site superintendent walks out on to the site, what they observe is a comprehensive picture, sort of their own augmented reality version of how things are going and how these interconnected issues can influence the overall success of the job. Knowing the location of people is part of ensuring the overall of success of the job. The location of people is important for the superintendent in ensuring that all tasks are being performed as they were planned and has to be viewed from this comprehensive picture of the superintendent's responsibilities. For the purpose of this research, only issues related to construction safety are considered, for location monitoring.

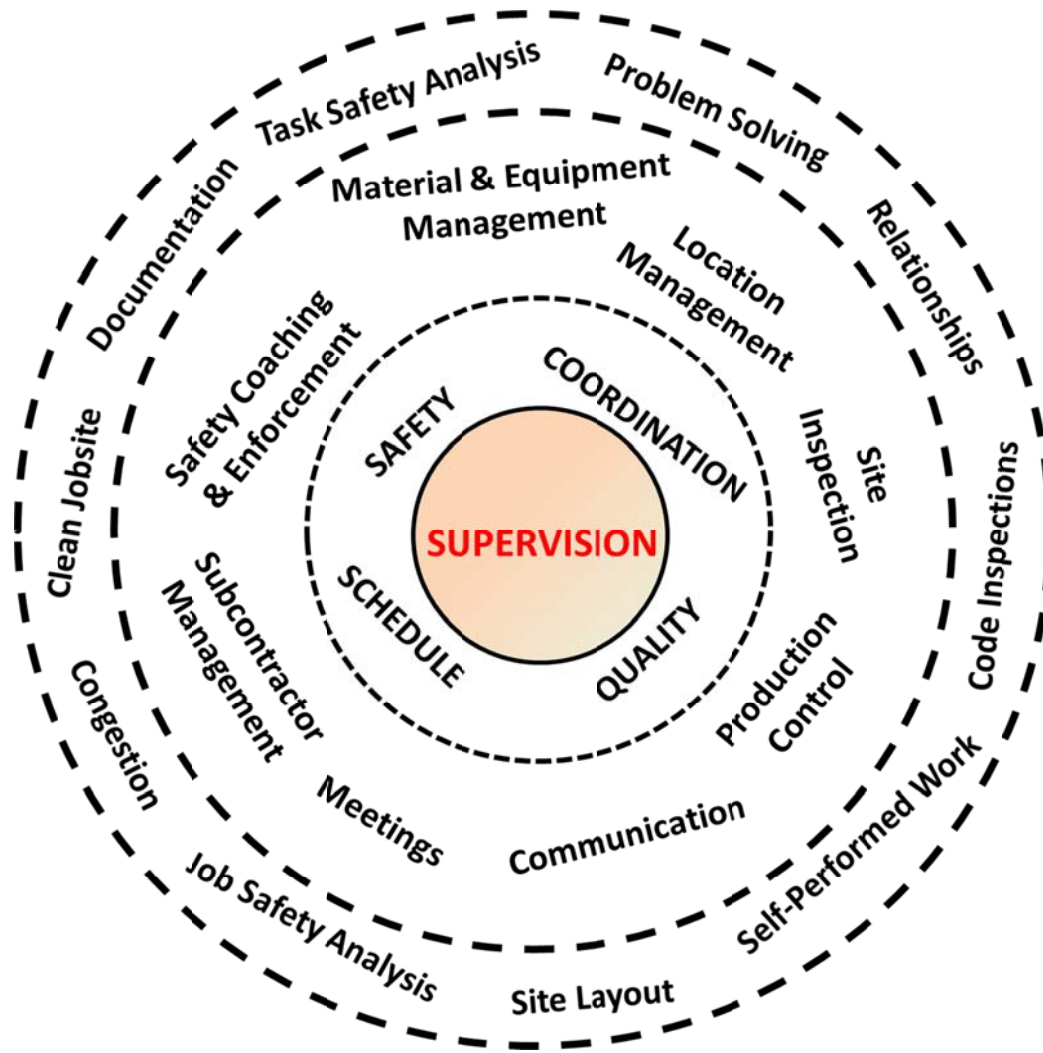


Figure 4.16: Comprehensive responsibilities of a construction site superintendent.

4.7 Interpretation of Results and Conceptual Framework Development

The data collected in the interviews was used to develop a conceptual framework for construction safety monitoring based on combining RFID and BIM technologies. This process involved counting recurring codes in trying to identify areas/situations that allowed the proposed solution to be used in implementing job site safety (IAR, University of Texas, 2007). The process of identifying themes from clusters of data had been recommended by Hycner (1985) in the process of analysing interview data from a

phenomenological standpoint. Bartlett (2004) defines ‘Code Density’ as the percentage of times a particular code has appeared during qualitative data analysis. For the purpose of this research, code density is the percentage of interviewees whose responses were associated with a particular code.

The need and usefulness of the proposed framework is demonstrated by considering the specific codes from the thematic analysis and content analysis of the interview data, as shown in Table 4.11. The codes presented in Table 4.11 were created when the construction superintendents were asked if they saw any benefit in using an RFID and BIM based system to track the movement of workers for safety purposes. From the content analysis perspective 95% of the superintendents interviewed thought that the proposed solution would be useful. The superintendents expressed several comments indicating that the proposed framework would be useful by looking at the thematic analysis results. The codes indicate a very high level of agreement among the interviewees about the usefulness of the proposed tool. Hence a need and usefulness for the framework for monitoring the movement of construction workers using RFID and BIM is thus established.

Thematic Analysis

- A tool like this could save some footsteps and time
- Any eyes that can show where people are, would be useful
- Any superintendent would be able to use this
- It is a necessity to know where everyone is, for both safety and productivity
- It would absolutely be a useful tool to have
- It would be very useful tool for the safety officers
- Since it is not possible to be everywhere, it would be a very useful tool to have
- There are benefits to the proposed method of tracking people
- This could be very useful on a large job

Quantitative Content Analysis

- It would be a good tool to have (95%)
- It would be useful to monitor productivity (58%)
- It would help me manage my time a bit more effectively (16%)
- You could track it against schedule, for coordination purposes (11%)
- It would be useful to track where people have been (11%)



**RFID + BIM
based
Supervision**

Table 4.11: Specific codes from qualitative thematic and quantitative content analysis demonstrating the need and usefulness of RFID + BIM based supervision tools

4.7.1 Colour Coded Crews

The interviewees were asked about the various ways they envisioned using the proposed framework. A particular scenario that emerged was to colour code the workers based on their trade to show them working in the various areas within the construction site. The results from the thematic analysis and the content analysis leading to the creation of the framework to track workers by colour coding them based on their trade is presented in Table 4.12.

Thematic Analysis

- Having the foreman for each crew with a circle could be useful
- It would be useful to colour code crews based on their role
- It would be useful to know when the foreman is not with his crew
- It would be useful to know when people enter a hazardous area
- It would be useful to see where a certain crew is, rather than go and search for them on a large site
- You can check to make sure that every crew is sufficiently staffed
- It would be useful to know when someone is not attending a safety meeting but are working on site
- If you know where a certain crew is, you can track that against the schedule
- It would be a good way of keeping up with where everyone is
- It would be a great tool to have, to monitor people throughout the day
- It would be useful to know all the areas where work is taking place
- It would be useful to know where all the visitors are on the site
- It would be useful to know where people are when hazardous activities are taking place

Quantitative Content Analysis

- It would be useful if crews are colour coded (21%)
- It is difficult if not impossible to know where everyone is (21%)
- Location of people is important because congestion can lead to accidents (11%)

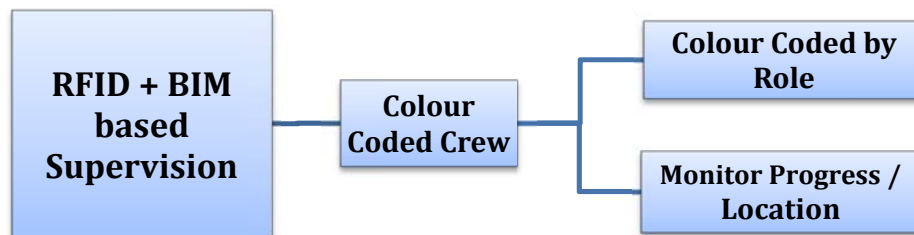


Table 4.12: RFID + BIM monitoring by colour coding construction workers based on their trade

From a thematic analysis standpoint, the interviewees mentioned that highlighting the crew foreman so they know when the foreman was not present with the crew would be useful. It was also suggested that the proposed method could also be used to track productivity, progress of work zones, know when workers entered hazardous areas, know the location of visitors on site, know when workers/crews miss safety meetings and in general would be a good way to track people. 21% of the interviewees suggested that it would be useful to track workers by colour coding them by trades and 21% of the interviewees also suggested that it is difficult if not impossible to track the location of workers within the construction site. 11% of the superintendents interviewed indicated that congestion could lead to accidents and an unsafe work environment. The proposed tool could allow the superintendent to instantly spot congested areas within the construction site.

In this scenario, crews will be colour-coded by their trade and their location will be tracked within the construction site. This method of tracking could be very useful in the construction of high-rise structures when several trades are working on different floors. An illustration of this scenario is shown in Figure 4.17. This is an illustration only of the proposed framework and this stage a working prototype had not been created. This figure can quickly show the superintendent when there are congested areas or when construction workers are present in areas they are not supposed to be in. One superintendent said, *“If you had the ability to have a three-dimensional view of such a thing for instance on high-rises when we’re pulling tables or something were moving up with concrete frames and what have you. Cranes are hoisting and everything else to have the ability to just take a look at that area now would be great.”*

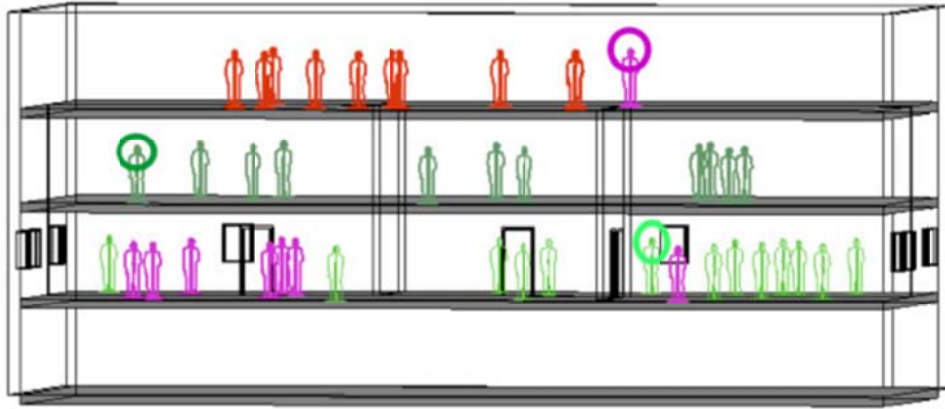


Figure 4.17: Illustration showing colour-coded tracking of construction workers using RFID + BIM.

The decisions a superintendent has to make by considering the illustration in the above scenario include the following considerations:

- Are the crewmembers working where they are expected to be working? If crewmembers are not working where they are expected to be, it is possible that they are moving about on the construction site. Workers moving around on the construction site can lead to accidents (HSE, 2003a). The superintendent can make a decision if intervention is required, based on the location of workers on the site.
- Is the trade foreman near the workers to oversee them? Direct supervision of workers is an important factor for positive safety outcomes (Lingard and Rowlinson, 1997). Absence of the supervising foreman may indicate an unsafe condition and may require an intervention from the site superintendent.
- Are too many trades at one location, congesting the site? Accident risks increase with congestion as risks vary for each crew, based on the type of work being performed (Weinstein et al., 2005). The superintendent can make an appropriate decision if too many trades are in one location, such as adjusting the schedule to move some workers out of the congested area.

- Are visitors to the site in authorised areas? Visitors are implicitly unaware of site conditions and may not have adequate knowledge of the safety risks in a particular area of the site. Therefore it would stand to reason that the construction team be aware of situations when visitors wander into unauthorised areas.
- Have any of the crews moved from one location to another? As crews move about within the site from location to location, safety risks change as the environmental and physical conditions may have been altered. Superintendents can use this opportunity to advise the crew about the modified safety conditions.

Only the superintendent (or the appropriate designee such as a safety officer or the area superintendent) is able to decide if intervention is needed, based on the scenario depicted in Figure 4.17. The decision may require the superintendent to adjust the schedule on the fly to prevent congestion or stop work if a trade foreman is not overseeing the working taking place. Alternatively, the superintendent may simply acknowledge that a particular trade crew (such as say electricians) must be spread out within the site to perform the work and decide to not intervene.

4.7.2 Emergency / Hazardous Situations

The thematic analysis data and the quantitative content analysis data were examined to verify scenarios in which the proposed framework could be used. One recurring theme was the use of the proposed framework to monitor people on the construction site during an emergency situation when the site may have to be evacuated and during situations when hazardous activities are taking place on the site. This resulted in the creation of a scenario for the framework presented in Table 4.13. Codes from thematic analysis and quantitative content analysis that contributed to this scenario are presented in Table 4.13.

Thematic Analysis

- It would be useful to know when people enter a hazardous area
- This would be very useful in the event of an emergency to know where everyone is
- The virtual solution must have an alarm system, instead of someone looking at the screen all day
- It would be very useful to conduct a headcount during an emergency evacuation
- It would be useful to highlight hazardous areas and send an alert when an unauthorized person enters
- It would be useful to know where people are when hazardous activities are taking place

Quantitative Content Analysis

- It would be good to have an alarm system (26%)
- It is important to know where everyone is during an emergency situation (26%)
- Hazards on a construction site are constantly changing, so it is important to know where everyone is working (21%)
- It would be useful during an emergency situation (16%)
- Sometimes people will go into areas they are not supposed to (11%)
- On larger jobs there are often times too many people for me to keep up with everyone (11%)

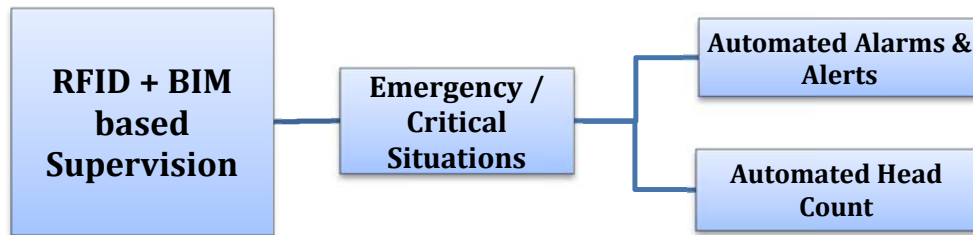


Table 4.13: RFID + BIM monitoring during emergency and critical situations

From the thematic analysis side, several codes indicating the use of the proposed scenario during an emergency situation, during an emergency evacuation and during hazardous activities occurring is suggested by the interviewees. Superintendents spoke about sending an alert when a worker enters a hazardous or unauthorized area. Currently they ensure authorized personnel by using hardhat stickers. The quantitative content analysis results indicated similar results as the thematic analysis but also included a quote indicating that the hazards on a construction site are constantly changing therefore it is important know the location of the workers.

If an accident were to happen on a construction site, the superintendent starts the emergency action plan where all workers are required to come to a pre-decided muster point. This procedure also includes a head count to verify that all workers on site are accounted for. The head count process could be tedious when a few hundred workers are present on site. Using RFID and BIM combination the superintendent would be able to see the location of any workers missing or to ensure that everybody is present at the muster point, as illustrated in Figure 4.18. This solution can assist in what one superintendent said *“I have also constantly tried to figure out a way to do an effective head count during an emergency evacuation at the rally point.”* “The same can be true when hazardous activities are taking place on the construction site, such as demolition. Certain crews that are not trained to be in areas where demolition is taking place or excavation is taking or a critical lift is taking place. A critical lift is when multiple cranes are needed to pick up an object or when a crane picks up an object that weighs more than 75% of the crane’s designated capacity (OSHA, 2001). The proposed solution would allow the superintendent to electronically monitor construction workers’ location when they are in the vicinity of danger. Incorporating telecommunication services and sending an alert to the superintendent and or worker about the danger can further automate this, so that the superintendent does not have to constantly monitor the movement of workers. One superintendent stated this about the proposed solution: *“For me personally, because I would rather walk the site, the biggest area I would use it for is to designate this area as off limit for these people. So if anyone else is in that area, then alert. If anyone that is in the demolition area alert, if someone is in the swing radius, alert.”*

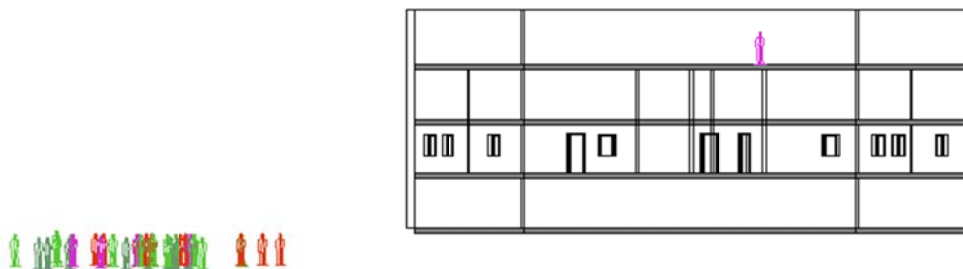


Figure 4.18: Illustration showing colour-coded tracking of construction workers using RFID + BIM during emergency evacuation.

This scenario allows the superintendent to consider the following issues from a safety perspective:

- Could the worker(s) be in danger because they enter an unauthorised zone?
- What is the best way to reach the worker if they are in an unauthorised zone?
- What is the best way of reaching worker(s) that did not heed the call for an emergency alert or emergency evacuation?
- What should be consequences for worker(s) if they venture into unauthorised zones or for not coming immediately to the muster point in the event of an emergency evacuation?

The superintendent can address the issue of worker(s) entering forbidden areas by directly intervening or may decide that it would be necessary for the worker to be in that area. Superintendent may decide that it is too dangerous to send someone or go personally to check on a missing person during an emergency evacuation. The superintendent is therefore enabled to make an appropriate decision about penalties for workers during and after an emergency/forbidden situation on the construction site, based on the severity of the issue identified.

4.7.3 Colour Coded by Zones

A scenario in which workers can be tracked by colour-coded zones within the construction site, based on whether or not they are in the correct zone is proposed, as shown in Table 4.14 The thematic analysis results indicate the proposed scenario for tracking based on pre-determined zones within the construction site. It was suggested that it would also be useful to send an alert to the superintendent when a worker enters a wrong or unauthorized zone. The quantitative content analysis results also suggested the use of the proposed framework in similar situations and also suggested that it would be useful to identify congested areas.

Thematic Analysis

- It would be useful to colour code areas and show workers when they are in the wrong area
- It would be useful to highlight hazardous areas and send an alert when an unauthorized person enters
- It would be useful to know all the areas where work is taking place
- It would be a good way of keeping up with where everyone is

Quantitative Content Analysis

- It would be useful to track people by zones and off-limit areas (21%)
- Hazards on a construction site are constantly changing, so it is important to know where everyone is working (21%)
- Sometimes people will go into areas they are not supposed to (11%)
- On larger jobs there are often times too many people for me to keep up with everyone (11%)

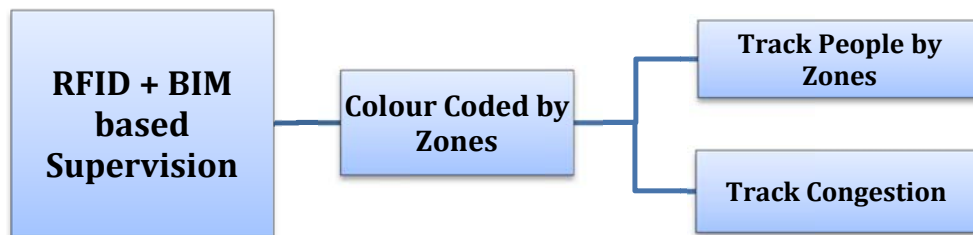


Table 4.14: RFID + BIM monitoring by colour coded zones within the jobsite

Instead of the superintendent looking at all the workers and identifying if they are in the correct place, this method would split the jobsite into various zones. Additionally all workers on site will be expected to be in certain areas, depending on what work is being done. If workers are not in the correct area, then those workers will be highlighted, thus suggesting to the superintendent that an action must be taken. An illustration of tracking people on the construction site in this manner is shown in Figure 4.19. One superintendent said: *“I think both productivity and safety would tie in together. Because you know where everybody is, you can, especially the way BIM is going right now; we can highlight critical areas and off-limit areas. You can colour code areas and say this is a safe area and that there is nothing happening. You can see where people should be and should not be.”*

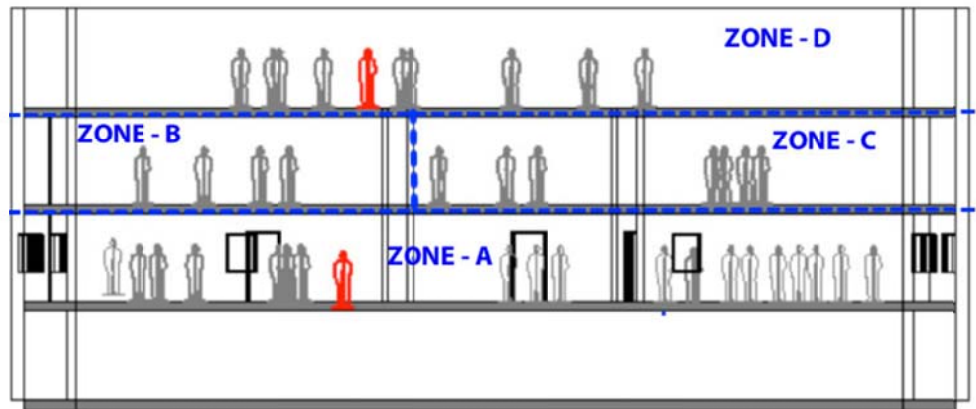


Figure 4.19: Illustration showing colour-coded tracking of construction workers using RFID + BIM, based on designated zones.

Similar to previous scenarios, the superintendent can use the information to consider the following issues, based on the illustration presented in Figure 4.19:

- What is the severity of the danger to worker(s) when they are in a location where they are not expected to be?
- What type of intervention is needed to rectify the situation?
- Are there areas of the construction site where there are too many crewmembers?

The superintendent may consider these questions and decide an appropriate course of action such as call the worker on a mobile phone in the wrong location or inform the worker's foreman of the situation before an incident may occur. The superintendent may intervene to ascertain why a certain zone of the construction site has no workers. These are decisions that a superintendent, who is the point person on the construction site, is able to make enabled by the proposed framework.

4.7.4 Remote Management

Among the various themes that emerged was the notion of using the proposed framework remotely. From a thematic analysis perspective, superintendents described occasions when they cannot be on the construction site, as they may have to attend meetings related to the project or the company. They remarked that the solution based on the proposed

framework could be useful in keeping up with the activities on the construction project. There were remarks made about how this could be a useful tool to have for the home office to determine progress of work and areas of the project where work is currently taking place. From a quantitative content analysis perspective, superintendents mentioned that while it was very difficult for them to know the location of construction workers throughout the site, it was more important for the crew foreman and subcontractor superintendents to know where their crew members are. The scenario created for this section of the framework is presented in Table 4.15.

Thematic Analysis	Quantitative Content Analysis
<ul style="list-style-type: none"> ○ Meetings and other communication issues with stake holders ○ Find a balance between monitoring day to day activities as well as communicating to stake holders ○ Sometimes I cannot be on the site and it would be a useful tool ○ It could be used from our home office as well 	<ul style="list-style-type: none"> ○ Each foreman should know where all his crewmembers are (42%) ○ Meetings (37%) ○ Communication (32%) ○ Subcontractors keep up with where their people are (32%)

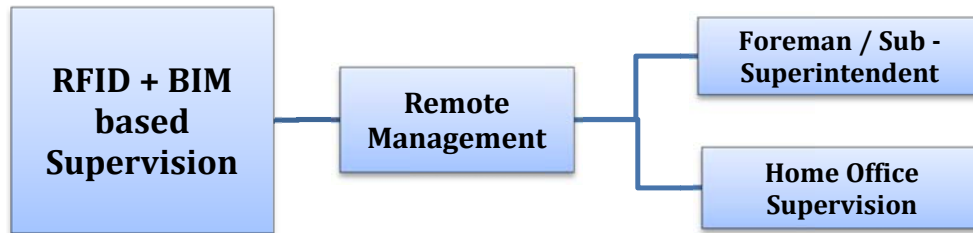


Table 4.15: Remote management of the construction site using RFID and BIM framework for

Superintendents spoke about examples where the subcontractor superintendent or the crew foreman is not always around the crew. For instance it is not uncommon for an electrical subcontractor to have workers all over the building as they are pulling wires from one end of the building to the other. The same can be true for a masonry subcontractor where work could be going on several different areas of the site. Site superintendents are often in meetings where they cannot oversee the work occurring on

the construction site. This could also provide some measure of oversight for the superintendent that cannot go to all areas of the jobsite. This can also be used for remotely monitoring the jobsite from the home office, if necessary, as illustrated in Figure 4.20. One interviewee pointed out that “*Any eyes that can show what is going on, where I can’t see would be helpful. I think any superintendent would be able to use this.*”

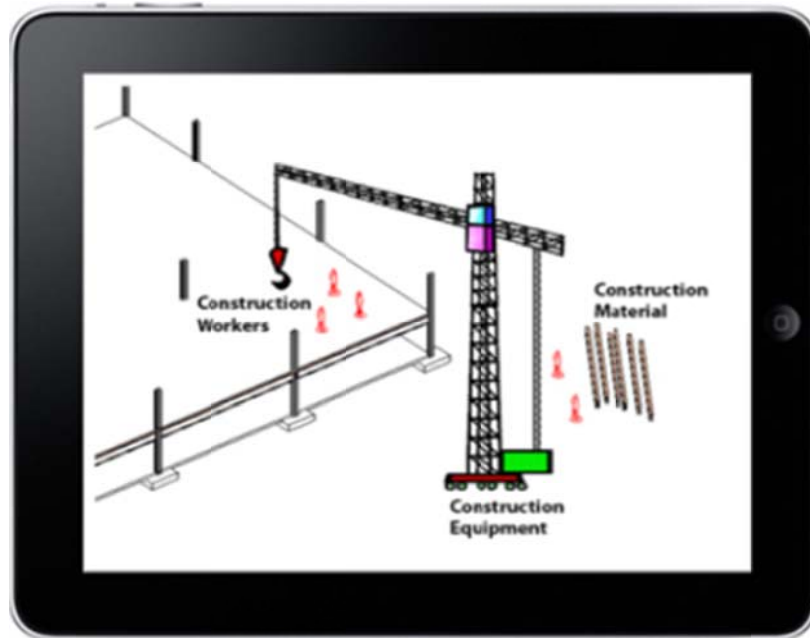


Figure 4.20: Illustration showing tracking of construction workers using RFID + BIM, on a tablet

The superintendent, foreman and sub-contractor superintendent can all use the scenario to consider issues such as:

- Are workers at the designated location within the site? Similar to superintendents, the subcontractor superintendent or foreman can be enabled to make safety related decisions based on the location of workers.
- Are workers moving at an appropriate pace to maintain optimum safety levels? Accidents can occur when workers are trying to increase productivity and catch up to the original schedule (Han et al., 2013). By assessing the pace of progress, supervisory personnel are enabled to intervene if deemed necessary.

- Have workers moved to a different location where the safety risks have changed? Safety risks on a construction site are constantly shifting within a construction site (Cigularov et al., 2013). By knowing the movement of workers within the site, supervisory personnel are enabled to make intervene and advise workers about the safety hazards at the new location. By remotely allowing the superintendent to know the movement of workers within site, the superintendent is enabled to either intervene personally or delegate the task to a responsible actor within the site.
- Is construction progressing as scheduled? Since experienced personnel in the home office are involved in crafting the safety plans at the beginning of the project, they can monitor the progress on site remotely, to gauge the safety hazards on site and intervene if necessary.

A superintendent, foreman or sub-contractor is uniquely situated to take into account the above issues and decide to intervene if necessary. The superintendent may decide to have a safety officer present when they have to attend a meeting or be at the home office, depending on the stage of the job and the risks involved in the on-going activities at the construction site.

4.7.5 Conceptual Framework

Four dominant themes emerged from the thematic analysis and quantitative content analysis of the interview data. These themes included '*Colour Coded Crews*', '*Emergency/Critical Situations*', '*Colour Coded by Zones*' and '*Remote Management*'. The scenarios described for these themes are combined and presented as the conceptual framework for monitoring the movement of construction workers within the construction site, as shown in Figure 4.21

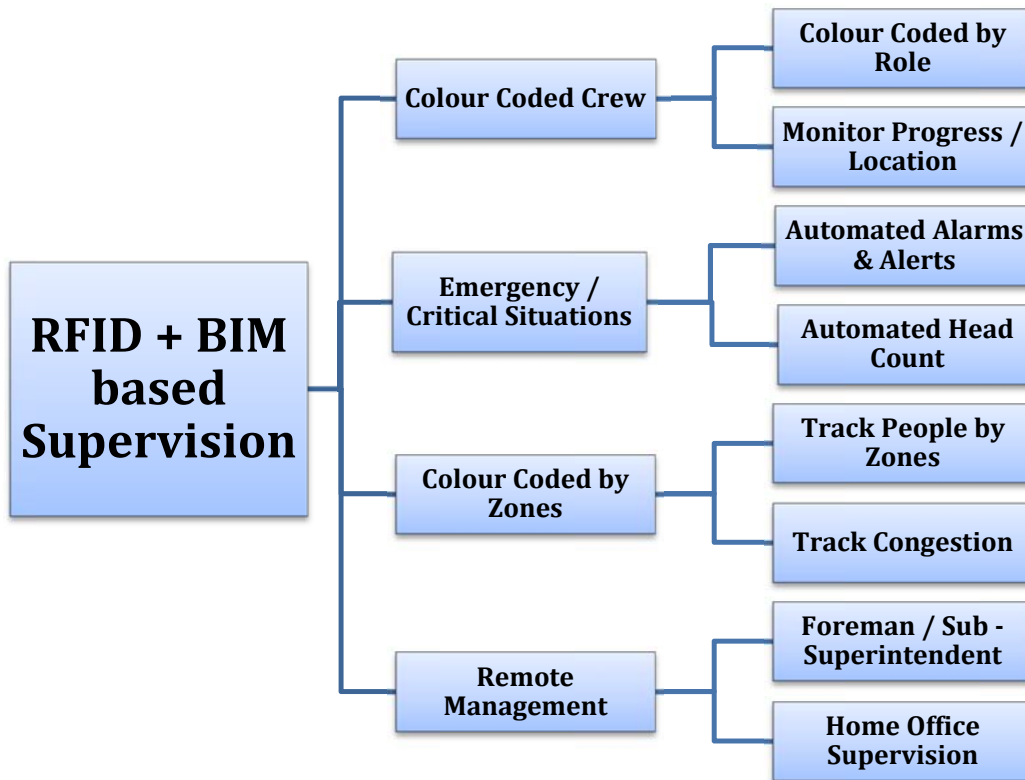


Figure 4.21: Conceptual Framework for RFID + BIM based safety supervision

The superintendent is uniquely situated on the construction site to quickly assess the safety risks on site by considering the location of workers, as he/she has a comprehensive understanding of the near term and long term activities and safety risks for specific activities. The decisions the superintendent may make are largely contextual and time sensitive, given the illustrations that can be gathered by the proposed framework of safety monitoring using RFID and BIM.

4.8 Summary

This research called for semi-structured interviews with construction site superintendents to understand their role in the overall process of a construction project and their perspective on implementing health and safety on a construction site. This chapter provided the details of conducting interviews with construction site superintendents. In an effort to be thorough in the analysis of the interview data, the transcribed text from the

interviews was analysed using thematic analysis techniques as well as quantitative content analysis techniques. The process of conducting the analysis and using the results for the creation of a conceptual framework to monitor the movement of construction workers within the construction site using RFID and BIM was presented. In the next chapter the process of validating the conceptual framework is presented.

CHAPTER 5

FRAMEWORK VALIDATION

5.1 Introduction

In the previous chapter, the development of a conceptual framework to monitor the movement of construction workers was presented. In this chapter the process of validating the conceptual framework is discussed. Details about the data collection and analysis procedures for the Internet survey instrument used in the validation process are described. The quantitative methods employed as part of this mixed method research are then presented in this chapter. The one hundred and thirty responses to the construction industry survey are analysed and conclusions drawn from the survey data are discussed.

5.2 Data Collection Procedures

A conceptual framework is based on several related concepts supported by phenomenon and framework specific philosophies (Jabareen, 2009). The framework proposed in this research aims to enable construction site safety supervision processes. The conceptual framework for this research was developed based on the results of conducting interviews with nineteen construction site superintendents (as presented in the previous chapter). The validation of this conceptual framework was conducted using an Internet survey of construction professionals. Over seventy e-mails were sent to construction professionals in the United States requesting their participation in the survey. Respondents were encouraged to forward the link for the survey to professionals within their company who might be able to contribute to the study (i.e. snowballing). The survey elicited one hundred and thirty responses from the construction professional community.

The survey consisted of eighteen questions/statements presented in six sections based on the context. Screenshots from the survey are presented in Appendix 5.2. Participants were first presented with ethical research statements that outlined the purpose of the survey and explained about their rights in the process of completing the survey. Participants had to agree to terms presented in the ethical consent section in order to continue and participate in the survey. Prior to beginning the survey, a two-minute video was shown to the participants, which briefly explained RFID technology and the differences between active and passive tags. The popular everyday use of this technology in retail shopping malls was described. The intended use of active RFID tags in a building information model to track construction workers was also briefly described. The purpose of the video was to

provide the respondents with some basic understanding of RFID and its intended use with BIM in the research. Screenshots used in the creation of the video are presented in Appendix 5.1.

The survey was split into six sections and the first section of the survey collected demographical information about the respondents. The next four sections of the survey presented the respondents with four scenarios and accompanying statements. These scenarios were the same ones that were developed in the conceptual framework. The respondents were then asked to rate each statement in an effort to elicit their level of agreement or disagreement, based on Likert data. Each statement in the survey provided the options ranging from ‘Strongly Agree’, ‘Agree’, ‘Neutral’, ‘Disagree’, and ‘Strongly Disagree’. Several of the statements made references to a ‘Tool’ and were done to ensure participants could imagine the proposed framework in an actual working environment. The use of open-ended questions is useful in finding out the issues that responders are most concerned about (Saunders et al., 2009); therefore participants were also given an opportunity to provide additional comments in each of the four scenarios presented. Each of the four scenarios was presented through a short description of the scenario, followed by an illustration depicting that scenario. The final section of the survey asked the respondents to rate a statement regarding the overall framework, based on the four scenarios presented. Participants were also offered an opportunity to provide any further concluding remarks and suggestions regarding the research. A total of thirteen statements using Likert item options and five open-ended questions were part of the survey.

5.3 Data Analysis Procedures

Asking survey respondents to select an option reflecting their level of agreement or disagreement about a statement was proposed by Resis Likert in 1932 and is named after him (Bertman, n.d.). Each individual question/statement in the survey is referred to as a ‘Likert Item’ and ‘Likert Scaled Data’ is when multiple questions/statements are combined for analysis purposes (Statistics Cafe, 2011). Descriptive statistics are suggested by Saunders et al. (2009) to report the central tendencies of Likert scale data. In the presentation of the findings of the survey data, questions relating to each scenario that emerged from the conceptual framework will be discussed individually in its own section

and the final Likert item testing the overall framework will be discussed in a separate section. Prior to the analysis, the data was coded numerically by assigning the values ‘5 = Strongly Agree’, ‘4 = Agree’, ‘3 = Neutral’, ‘2 = Disagree’ and ‘1 = Strongly Disagree’. The following statistical tools will be used to present the data:

- **Cronbach’s Alpha:** Internal consistency is the concept of correlating responses to a question with all other responses within the questionnaire to ensure consistency (M. Saunders et al., 2009). Cronbach’s Alpha is the most common method of checking internal consistency of Likert data (Saunders et al., 2009). Cronbach’s Alpha will be used to check for internal consistency of the data, as suggested by Saunders et al. (2009) and Gliem & Gliem (2003). This analysis is conducted for all the Likert item responses and not for each individual item, as suggested by Gliem & Gliem (2003).
- **Central Tendency:** Likert items are considered as ‘Ordinal’ data and descriptive statistics are suggested for analysing this type of data (Bertman, n.d.). However, Norman (2010) has suggested that Likert data have been reported as continuous data in scientific journals for a number of years and can be analysed using techniques appropriate for continuous data, in the interest of getting a robust understanding of the data. Descriptive statistics using bar charts, mode (i.e. the value that occurs most often), median (i.e. the middle value of the data after the data is ranked) and mean (i.e. average rating using the numerical scale) will be used to present the central tendencies of the data.
- **Data Dispersion:** Data dispersion is used to show the variance in the data, putting the central tendencies of the data in perspective. The interquartile range and standard deviation will be used to show dispersion within the data for each individual Likert item. The interquartile range shows the difference between the highest and lowest values for the middle fifty per cent of the data and is considered an acceptable form of reporting dispersion (Saunders et al., 2009). The standard deviation shows the variation in the responses and provides an additional measure to understand the mean value for the data.
- **Experienced Respondent Results:** Respondents who have had more than fifteen years of experience in the construction industry may be considered to have a richer perspective of construction operations. Their ratings for the proposed framework are

computed separately to further probe the data. Their responses are separately presented to provide an understanding of how more experienced construction professionals felt about the proposed framework.

- **Summary:** A summary for each of the four scenarios and the overall framework will present a comprehensive assessment of the data at end of each section. The responses to open ended questions will be analysed using deductive thematic analysis. The thematic analysis will divide the written responses from the open-ended questions into ‘Positive Feedback’ and ‘Cautious Approach’ categories. Since the purpose of conducting the survey was to validate the conceptual framework (i.e., do construction professionals agree with the proposed method of safety monitoring), categorising the comments into ‘Positive Feedback’ and ‘Cautious Approach’ is appropriate. The comments that agree with the framework will be placed in the ‘Positive Feedback’ category and comments that disagree with the framework or point to concerns about the framework will be placed in the ‘Cautious Approach’ category. This analysis will also provide an additional backdrop for interpreting the statistical results and understanding how construction professionals view the framework.

5.4 Cronbach’s Alpha for Internal Consistency

Cronbach’s alpha is an acceptable and most common method for checking the internal consistency of data (Field, 2013). However, the use of Cronbach’s alpha is suggested when the questions/items used are measuring a related construct. In the case of this research, all statements are presented to validate the conceptual framework for combining RFID and BIM technologies to monitor the movement of construction workers on a site. Cronbach’s alpha as calculated for the Likert items in the statistical software ‘Minitab’ is presented in Table 5.1. Gliem & Gliem (2003) propose that if the alpha value is above 0.8, it indicates good internal consistency of the data. The alpha for the 130 responses over the thirteen statements was found to be 0.8682, well above the recommend threshold of 0.8 for the data to be considered internally consistent. Furthermore, deleting any particular statement from the calculations has a negligible effect on the alpha for the entire data, as shown in Table 5.1.

Omitted Item Statistics	
Statement	Cronbach's Alpha
Statement 1: Scenario 1	0.8602
Statement 2: Scenario 1 - A	0.8619
Statement 3: Scenario 1 - B	0.8647
Statement 4: Scenario 2	0.8618
Statement 5: Scenario 2 - A	0.8616
Statement 6: Scenario 2 - B	0.8601
Statement 7: Scenario 3	0.8509
Statement 8: Scenario 3 - A	0.8607
Statement 9: Scenario 13 - B	0.8504
Statement 10: Scenario 4	0.8560
Statement 11: Scenario 4 - A	0.8569
Statement 12: Scenario 14 - B	0.8654
Statement 13: Overall Framework	0.8526
Cronbach's Alpha = 0.8682	

Table 5.1: Cronbach's Alpha for Likert items in the questionnaire

5.5 Demographics

In section one of the survey demographical information about the participants was collected. Information about the annual revenue of the companies they represented and the type of companies they represented was collected. The role each participant plays in their individual companies, along with the number of years they have been working in the construction industry was collected.

87% of the respondents identified their company as a general contractor. The data presented in Figure 5.1 shows the distribution of participants based on their companies' annual revenue. The bar chart shows the number of participants that indicated their company revenue in a particular category. The italic values shown on the bar chart represent that category of company revenue, as a percentage of the overall respondents. As a point of reference, 97% of the top 100 contractors in the ENR have revenue of more than \$600 million, 92% of the contractors between 100-200 top contractors in the US

have revenues of more than \$300 million and less than \$600 million (ENR, 2013). Among the top 400 contractors in the US, all contractors have annual revenue of over \$100 million. ENR magazine publishes an annual list of top 400 contractors in the US. Based on the data collected, 80% of the participants are members of the top 400 contractors in the US. However, it is likely that several companies were represented multiple times in this data. It is not possible to know how many companies were represented multiple times, as participants were not asked to provide identifying information, due to ethical considerations. Regardless, with a high number of participants representing large construction companies, the feedback from the survey respondents would be significant if the framework were to be implemented on large projects. Moreover, the analysis of interview data with superintendents indicated that the proposed framework could be useful on large construction sites.

Size of Companies Represented by Participants

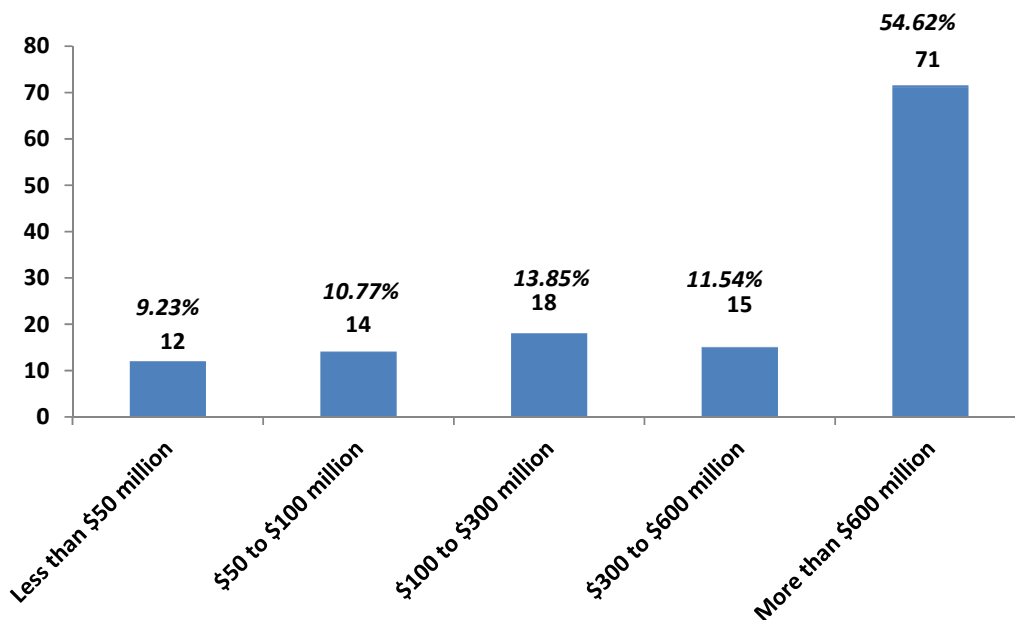


Figure 5.1: Company size of survey respondents

The data presented in the Figure 5.2 shows the distribution of participants based on their individual roles within their companies. Participants that may be categorised as field personnel are presented in red colour, including assistant project managers, assistant superintendents, field engineers, project managers, safety officers and superintendents. Participants that identified themselves in a site based role accounted for nearly 80% of all respondents. It must also be noted that most construction companies prefer their office personnel to have some previous site experience (Akintoye and MacLeod, 1997). Therefore it may be assumed that most or all respondents to this survey have had site experience in the construction industry and are familiar with the safety practices of the a construction site, implying that all respondents are qualified to give feedback about the framework.

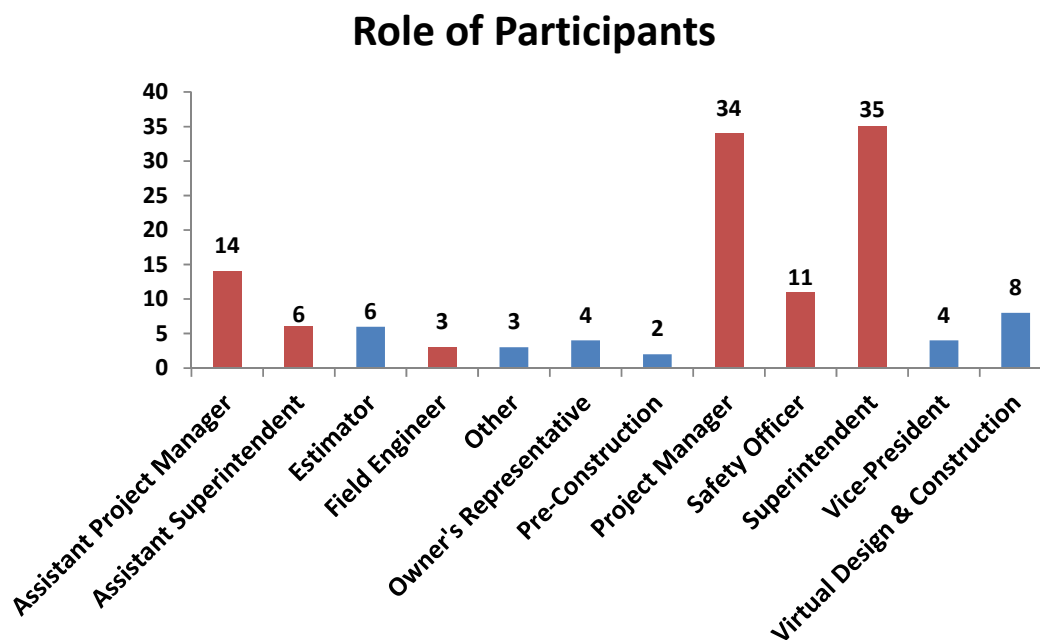


Figure 5.2: Current roles of survey respondents

The experience of construction professionals participating in the survey is shown in Figure 5.3. The data presented indicates that 55% of the respondents had over ten years of experience, 36% had over fifteen years of experience and over 80% of the respondents

have had more than five years of experience in the construction industry. A further analysis of the data for only the field personnel indicated that approximately 55% of the field personnel have had more than ten years of experience and approximately 83% of the field personnel have had more than five years of experience. These numbers indicate that the respondents may be considered knowledgeable about the safety practices on a construction site.

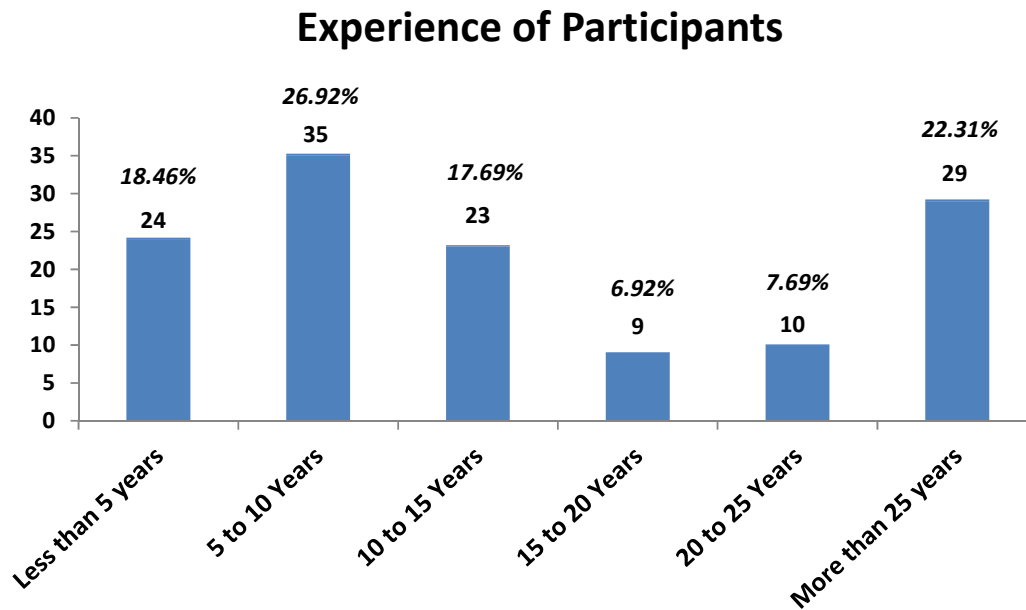


Figure 5.3: Years of construction experience of survey respondents

5.6 Colour Coded Crews

Luria et al (2008) have shown that direct supervision results in improved safety related behaviours in workers. Interviews with construction superintendents have revealed that direct supervision of all workers on a construction site is not possible due to the dispersed nature of activities occurring at any given time on a construction site. Therefore virtual monitoring of workers is proposed in this research using RFID and BIM.

In the case of scenario one, the proposed framework for monitoring construction workers on the site was presented, as shown in Figure 5.4. Participants were presented with a description of the scenario along with an illustration depicting the scenario in action.

Participants were then presented with three statements for this scenario and had to choose an option ranging from ‘Strongly Agree’ to ‘Strongly Disagree’ depicting how they felt about each statement.

“By combining RFID with BIM, crewmembers can be shown by using distinct colours, based on their trade and highlight the location of the trade superintendent (highlighted by the circles in the figure below). This figure can quickly show the superintendent when there are congested areas or when workers are present in dangerous areas where they are not trained to be working. It can also be used to monitor the progress of construction.”

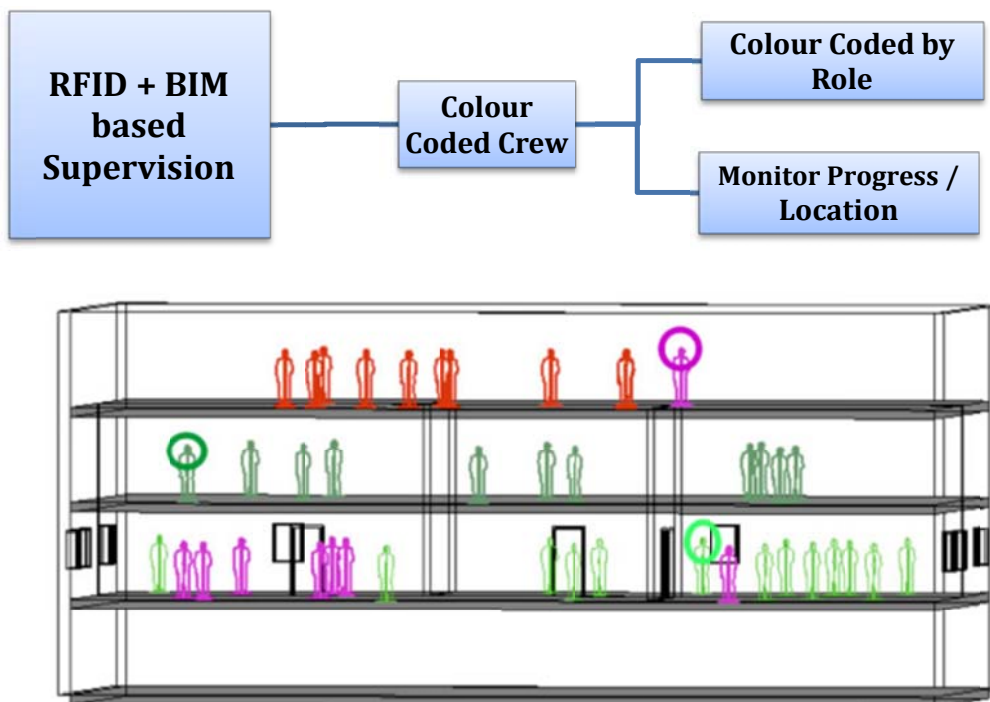


Figure 5.4: Scenario 1 for tracking construction workers using RFID & BIM

5.6.1 Scenario 1 – Real Time Tracking

Participants were presented with the statement *"The tool described will facilitate the superintendent to see, in real time, colour coded crew members at various locations within the site"* and were asked to rate their level of agreement or disagreement about the statement. More than 95% of the respondents agreed that the proposed tool would facilitate the construction superintendent to see the location of construction personnel, in

real time, within the construction site, as shown in Figure 5.5. None of the respondents disagreed with the proposed statement that construction workers can be tracked in real time using the proposed tool.

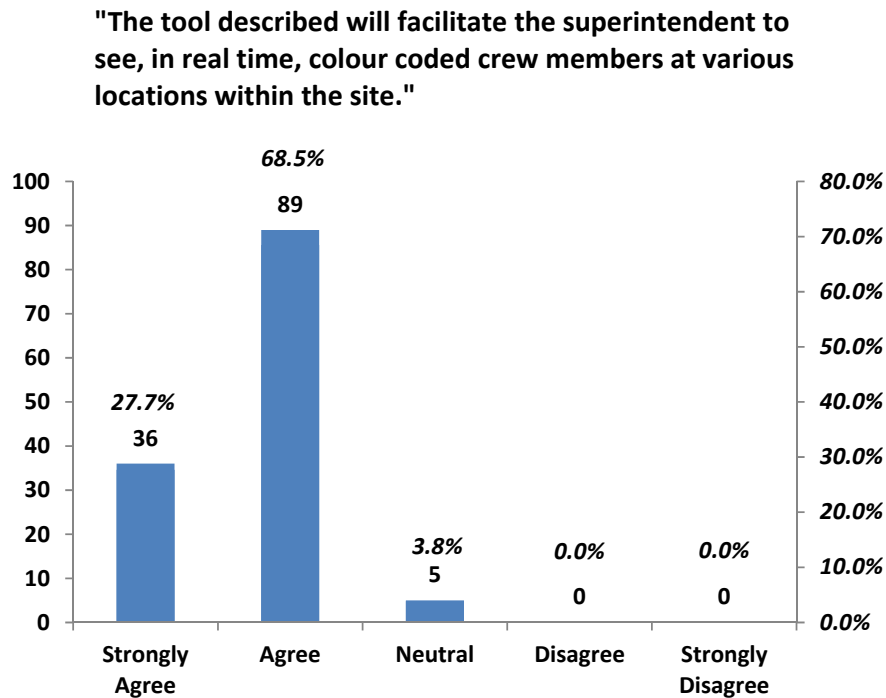


Figure 5.5: Tracking construction workers at various locations within the construction site

Statistical data presented in Table 5.2 indicate that construction industry professionals are in agreement that the proposed framework will facilitate the construction superintendent to see in real time, colour coded crewmembers at various locations within the construction site. The data revealed a median value of '4.0', a mean value of '4.2385' and a mode value of '4.0' for scenario 1, as shown in Table 5.2. The standard deviation for the data was '0.5104' interquartile range for the data for scenario 1 was '1.0', as shown in Table 5.2.

"The tool described will facilitate the superintendent to see, in real time, colour coded crew members at various locations within the site."				
Median	Mode	Mean	Standard Deviation	Interquartile Range
4.0	4.0	4.2385	0.5104	1.0

Table 5.2: Central tendencies and data dispersion for scenario 1 based on all responses

The data for personnel who have over fifteen years of experience has shown that there is agreement within them also about the usefulness of the proposed scenario, as shown in Table 5.3. The median and mode were found to be '4.0' and the mean was '4.1875' with a standard deviation of '0.4906'. The interquartile range was '0.0' within the respondents with over fifteen years of construction experience.

"The tool described will facilitate the superintendent to see, in real time, colour coded crew members at various locations within the site."				
Median	Mode	Mean	Standard Deviation	Interquartile Range
4.0	4.0	4.1875	0.4906	0.0

Table 5.3: Central tendencies and data dispersion for scenario 1 based on responses from personnel with more than fifteen years of construction industry experience

5.6.2 Scenario 1A – Tracking based on Role

Participants were presented with the statement " *The tool described will facilitate the superintendent to see, in real-time colour coded crews by their role (example: a halo around the HVAC crew foreman) at various locations within the site*" and were asked to rate their level of agreement about the statement. More than 92% of the respondents agreed that the proposed tool will allow the superintendent to see crewmembers, based on

their role, within the construction site. Only two respondents disagreed with the statement presented, as shown in Figure 5.6.

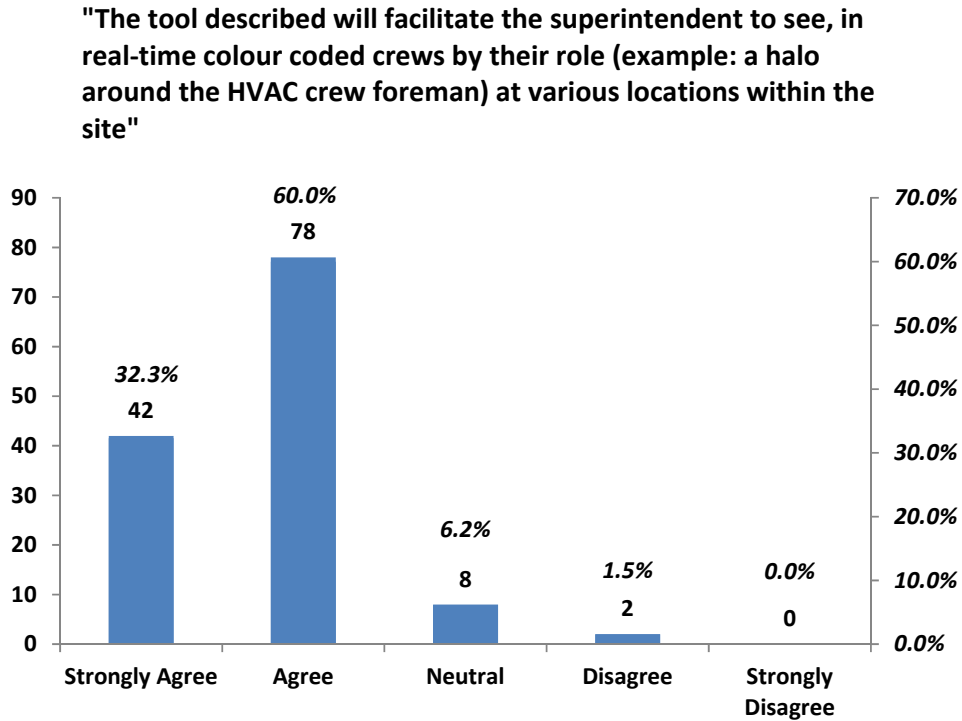


Figure 5.6: Tracking construction workers using colours to differentiate between trades

The statistical data presented in Table 5.4 indicates that there is overwhelming agreement among construction professionals that the proposed framework will facilitate the construction site superintendent to see colour coded crewmembers, based on their role. The data revealed a median value of '4.0', a mode value of '4.0' and mean value of '4.2308' for scenario 1A, as shown in Table 5.4. The standard deviation was found to be '0.6292' and the interquartile range for the data for scenario 1A was '1.0'.

"The tool described will facilitate the superintendent to see, in real-time colour coded crews by their role (example: a halo around the HVAC crew foreman) at various locations within the site"				
Median	Mode	Mean	Standard Deviation	Interquartile Range
4.0	4.0	4.2308	0.6292	1.0

Table 5.4: Central tendencies and data dispersion for scenario 1A based on all responses

The data for personnel who have over fifteen years of construction experience has shown that there is very high agreement within them also about the usefulness of scenario 1A, as shown in Table 5.5. The median and mode were found to be ‘4.0’ and the mean was ‘4.1250’ with a standard deviation of ‘0.6058’. The interquartile range was ‘0.0’ within the respondents with over fifteen years of construction experience.

"The tool described will facilitate the superintendent to see, in real-time colour coded crews by their role (example: a halo around the HVAC crew foreman) at various locations within the site"				
Median	Mode	Mean	Standard Deviation	Interquartile Range
4.0	4.0	4.1250	0.6058	0.0

Table 5.5: Central tendencies and data dispersion for scenario 1A based on responses from personnel with more than fifteen years of construction industry experience

5.6.3 Scenario 1B – Tracking Progress of Work

Participants were presented with the statement *"The tool described provides the superintendent an additional means to estimate the progress of work, based on the location of the colour coded crews"* and were asked to rate their level of agreement about

the statement. Over 50% of the respondents agreed with the proposed statement that the solution proposed would provide an additional means to the superintendent to track the progress of work by using the location of crews by trade. 14% of the respondents disagreed with the statement. More than 36% of the responses indicated a neutral stance to the proposed statement, as shown in Figure 5.7. The comments section for this scenario was further analysed to understand the feedback from the Likert data. Some of the respondents mentioned that the presence of workers does not necessarily indicate the production of work, as evidenced by the comment *“I do not see how this would show progress of work, but rather quantity of workers in a specific area at a time”*. However, some of comments mentioned that it could be used to track production, as evidenced by the comment *“This will work as a tracking device that could assist in monitoring production”*. It must be noted that the proposed tool is only offered as an additional means to measure the progress of work and not intended to be used as the primary tool to gauge progress of construction. This particular scenario is included in the framework since workers move within the site and hazards on the site change, as evidenced by the comments from construction superintendents in the interview phase of this research. Therefore when a superintendent sees a crew move to a different location, they may use that opportunity to advise the workers about the hazards in the new location and inspect the work that has been completed at the previous location.

"The tool described provides the superintendent an additional means to estimate the progress of work, based on the location of the colour coded crews"

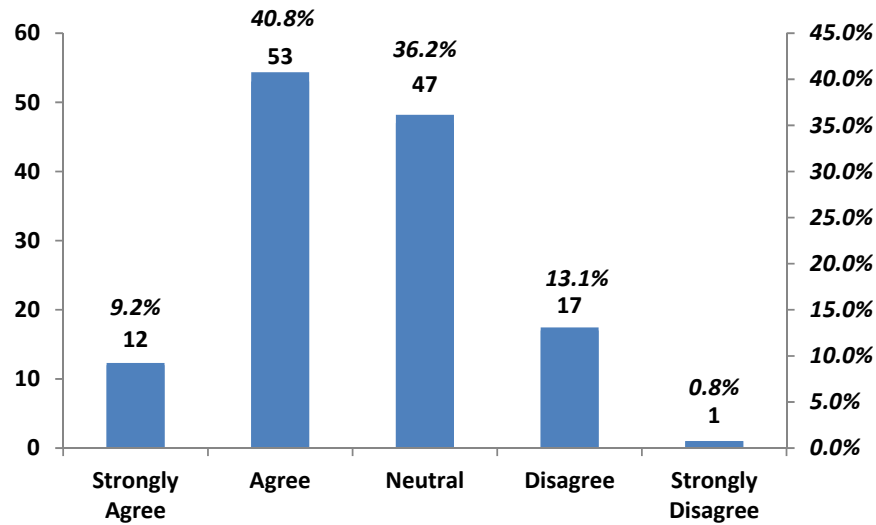


Figure 5.7: Tracking progress of work using location of colour coded crews

The responses indicate that 14% of the respondents disagreed with the proposed statement and 36% chose the neutral option. Statistical data concurred with this finding and revealed a median value of '3.5', a mode value of '4.0' and mean value of '3.4462' for scenario 1B, as shown in Table 5.6. The standard deviation was found to be '0.8632' and the interquartile range for the data for scenario 1B was '1.0'. These numbers indicate that there is some level of disagreement as well as ambiguity about this aspect of the scenario. However more than 50% of the respondents agreed with the proposed statement that superintendents could use the proposed tool to monitor the progress of work.

"The tool described provides the superintendent an additional means to estimate the progress of work, based on the location of the colour coded crews"				
Median	Mode	Mean	Standard Deviation	Interquartile Range
3.5	4.0	3.4462	0.8632	1.0

Table 5.6: Central tendencies and data dispersion for scenario 1B based on all responses

The data for personnel who have over fifteen years of experience has shown that there is a similar level of agreement within them about the usefulness of scenario 1B, as compared to the overall responses. The median value was '3.0', the mode was '3.0' and the mean was '3.4170' with a standard deviation of '0.9420', as shown in Table 5.7. The interquartile range was '1.0' within the respondents with over fifteen years of construction experience. While the mean indicates that more respondents agreed with this statement, the standard deviation however shows a wide range in the results. The comments section to this open-ended question provided a better perspective of the results and is discussed in the summary section of this scenario.

"The tool described provides the superintendent an additional means to estimate the progress of work, based on the location of the colour coded crews"				
Median	Mode	Mean	Standard Deviation	Interquartile Range
3.0	3.0	3.4170	0.9420	1.0

Table 5.7: Central tendencies and data dispersion for scenario 1B based on responses from personnel with more than fifteen years of construction industry experience

5.6.4 Summary of ‘Colour Coded Crews’ Scenario

The comments concerning the scenario to track the movement of workers by colour coding the crew were analysed using Atlas.Ti software. Comments that leaned towards ‘Positive Feedback’ are presented in Table 5.8. Comments indicate that construction professionals see value in this tool for the superintendent to monitor safety as well as productivity, as evidenced by the comment “*I truly hope to get the chance to use this system, I can see production going up and job site injuries lowered tremendously*”. Comments indicate that construction professionals view the proposed solution useful beyond monitoring construction safety, such as optimizing schedules, change order verification and to ensure that foreman for each crew is working alongside their respective crewmembers.

Positive Feedback	
<ul style="list-style-type: none"> ○ By tracking number of workers in areas alongside productivity, future schedules can be improved ○ Change orders can be verified against number of people working in the area changes were made ○ Could be a valuable tool ○ I truly hope to get the chance to use this system ○ Injuries could be lowered tremendously ○ Interesting concept ○ It would ensure that workers are being properly supervised ○ It would show number of workers in an area ○ More ways to monitor progress is always useful 	<ul style="list-style-type: none"> ○ Superintendent can see if workers in a wrong location ○ Superintendent can track work flow ○ Superintendent will be assisted by this tool to monitor production ○ This correct as an 'Additional Means' ○ This tool will improve production ○ This will be a big help to monitor safety ○ This would show foreman are working where they are supposed to be ○ Will allow the GC to verify the numbers of hours each person is working ○ Would allow superintendent to verify the work completed

Table 5.8: Codes derived from comments about scenario 1 leaning towards positive feedback to tracking workers by colour coding crew members using RFID and BIM

Comments that leaned towards disagreement or suggestion or other feedback are categorised under a ‘Cautious Approach’ are presented in Table 5.9. Comments indicate

that the size of a crew or location of workers does not indicate productivity and that it would only show the location of workers, as evidenced by the comment “*Presence is not necessarily production. Not sure how mere presence would help the superintendent know what is being done*”. Respondents caution that BIM models will need substantial input from superintendents and 4D schedules must be used as well as regularly updated for this concept to work. Respondents also felt that there might resistance from workers to wear the RFID tag. Responses indicate that the tool will only show the location of workers and will not show if the work is being done safely.

Cautious Approach	
<ul style="list-style-type: none"> ○ 4D Schedules will have to be implemented for this concept to work ○ 4D Schedules will have to be updated regularly ○ Crew size alone does not indicate productivity ○ It will only show where workers are present 	<ul style="list-style-type: none"> ○ Location of workers does not indicate production ○ Might get resistance from workers ○ Substantial input needed during preparation of the BIM model ○ Superintendent must personally verify productivity ○ Won't show if work is being done safely

Table 5.9: Codes derived from comments about scenario 1 advocating a cautious approach to tracking workers by colour coding crew members using RFID and BIM

There was over 90% agreement from respondents that the proposed tool would allow the superintendent to see construction workers by colour coding them based on their trade as well as by role and that it would be a useful tool for construction superintendents, as shown in Table 5.10. By considering the number of respondents agreeing versus disagreeing to scenario 1B, that this tool provides the superintendent an additional means to estimate productivity, the data shows 50% agreed with the notion while 14% disagreed. Therefore, while there appears to be some scepticism regarding scenario 1B, the numbers still indicate that more construction professionals agreed with the scenario than disagreed. The statistical analysis and the thematic analysis point towards the proposed tool as being useful for a construction superintendent. Therefore the scenario to track construction

workers by colour coding them by trade, within the context of the overall framework, may be considered as validated.

Statement	Agree	Neutral	Disagree
Scenario 1	96%	4%	0%
Scenario 1A	92%	6%	2%
Scenario 1B	50%	36%	14%

Table 5.10: Snapshot view of data showing levels of agreement, neutrality or disagreement regarding scenario 1

5.7 Emergency & Critical Situations

Hislop (1999) suggests that emergency preparedness for situations such as explosions, fire, release of hazardous materials, etc. is a critical aspect of a safety plan on a construction site. Interviews with site superintendents indicate that the emergency plan at a construction site includes a pre-determined muster point where personnel gather in the event of an emergency. Part of the emergency plan also involves conducting emergency evacuation simulations at key, pre-determined phases of the construction process. The use of the proposed framework for tracking construction workers during an emergency situation is proposed in scenario 2. Participants were presented with the description and the associated illustration shown in Figure 5.8. This scenario is proposed to automate the headcount process in the event of an emergency evacuation as well as warn the superintendent by using telecommunication systems when a worker enters an unauthorised area or a hazardous area. The proposed system can also provide an alert to the construction workers as well as using telecommunication systems.

“If an accident were to happen on a construction site, the superintendent starts the emergency action plan where all workers are required to come to a pre-decided muster point and begin the head count process. Using RFID and BIM combination the superintendent would be able to see the location of any workers missing or to ensure that everybody is present at the muster point (as illustrated in the figure below). By incorporating telecommunication services, an alert may be sent to the superintendent and/or worker when a person enters a dangerous area, further automating this process.”

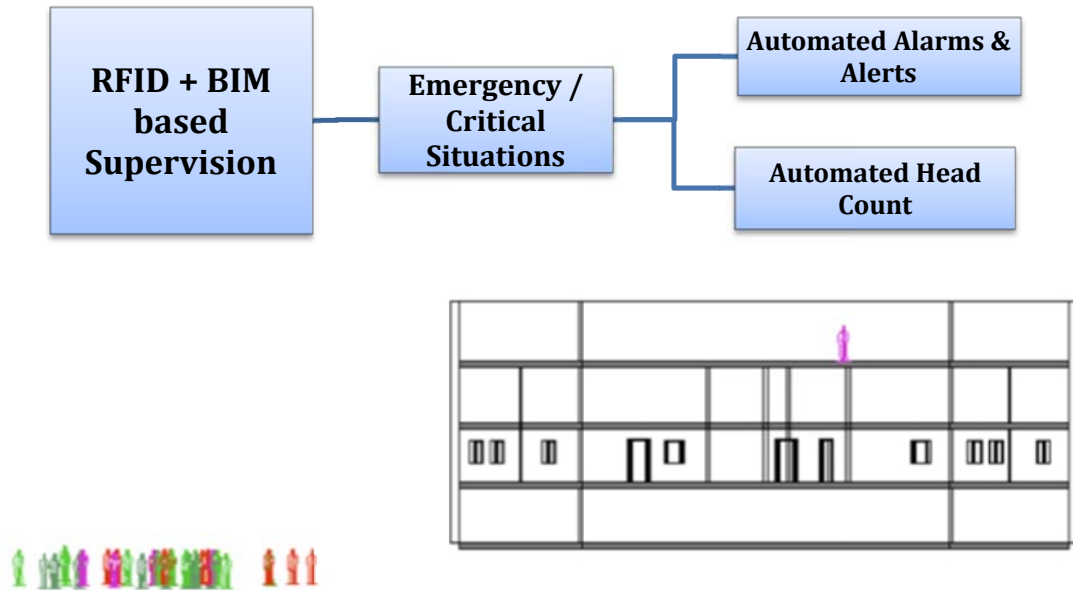


Figure 5.8: Scenario 2 for tracking construction workers using RFID & BIM during emergency situations

5.7.1 Scenario 2 - Usefulness During an Emergency Situation

Respondents were asked to rate their level of agreement about the statement "A tool that shows the real-time location of workers on the site, during an emergency situation will assist the superintendent", ranging from 'Strongly Agree' to 'Strongly Disagree'. Over 97% of the respondents agreed that the proposed tool would be useful to the construction superintendent during an emergency situation on the construction site. The results indicate that none of the respondents disagreed with the statement presented in this scenario, as shown in Figure 5.9.

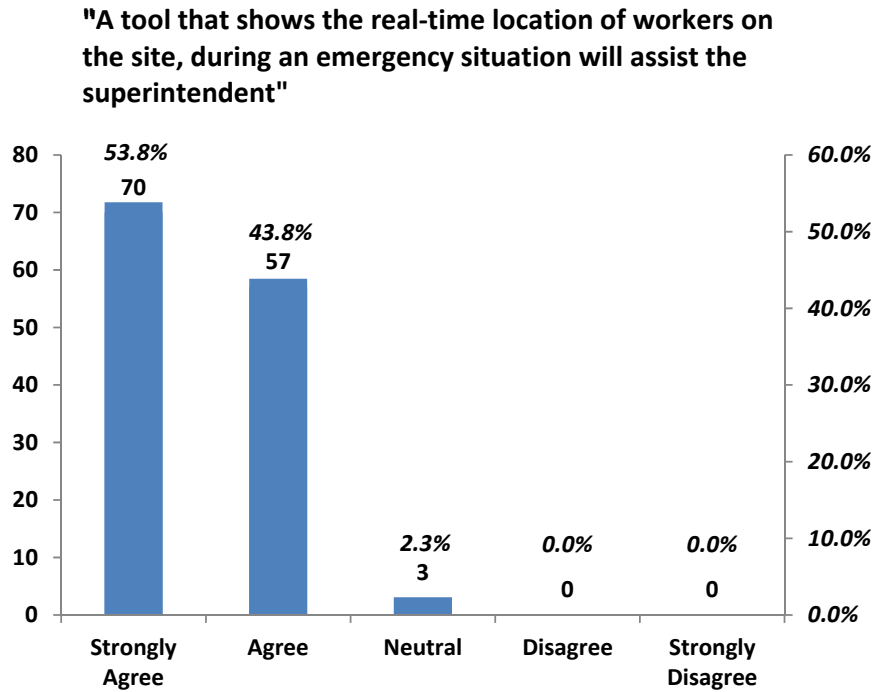


Figure 5.9: Scenario 2 for tracking construction workers using RFID & BIM during emergency situations

The responses indicate overwhelming acceptance of the proposed scenario regarding the usefulness of the proposed framework in emergency situations on a construction site. The statistical analysis for this data revealed a median value of '5.0', a mode value of '5.0' and mean value of '4.5154' for scenario 2, as shown in Table 5.11. The standard deviation was found to be '0.5461' and the interquartile range for the data for scenario 2 was '1.0'.

"A tool that shows the real-time location of workers on the site, during an emergency situation will assist the superintendent"				
Median	Mode	Mean	Standard Deviation	Interquartile Range
5.0	5.0	4.5154	0.5461	1.0

Table 5.11: Central tendencies and data dispersion for scenario 2 based on all responses

The data for personnel who have over fifteen years of experience has shown that there is agreement among them too, about the usefulness of scenario 2, as revealed by the statistical data shown in Table 5.12. The median value was '4.0', the mode was '4.0' and the mean was '4.4583' with a standard deviation of '0.5442'. The interquartile range was '1.0' within the respondents with over fifteen years of construction experience.

"A tool that shows the real-time location of workers on the site, during an emergency situation will assist the superintendent"				
Median	Mode	Mean	Standard Deviation	Interquartile Range
4.0	4.0	4.4583	0.5442	1.0

Table 5.12: Central tendencies and data dispersion for scenario 2 based on responses from personnel with more than fifteen years of construction industry experience

5.7.2 Scenario 2A – Sending Automated Alarms

The location of construction workers will be known using the proposed framework, by using RFID tags within a BIM. Also, the superintendent has a keen understanding of dangerous areas within the construction site and about workers that are qualified to work in those areas. Hence, a system can be developed whereby a construction worker can be

sent an alarm on their mobile phone or device to stay out of the dangerous area. Participants were presented with the statement *"If a tool can send an automated alarm to a construction worker when they enter a forbidden area, it will facilitate the superintendent by acting as an additional measure to monitor safety"* and were asked to choose an option that described their opinion towards statement, ranging from 'Strongly Agree' to 'Strongly Disagree'. The results indicate that more 95% of them agree with the proposed statement, as shown in Figure 5.10. The comment *"I can see this tool being helpful for projects in or near sensitive environments where workers have very restricted access to parts of the facility (i.e. healthcare)"* indicates the sentiments of the respondents. Less than 2% of the respondents disagreed with the proposed statement, while 1.5% indicated a neutral stance.

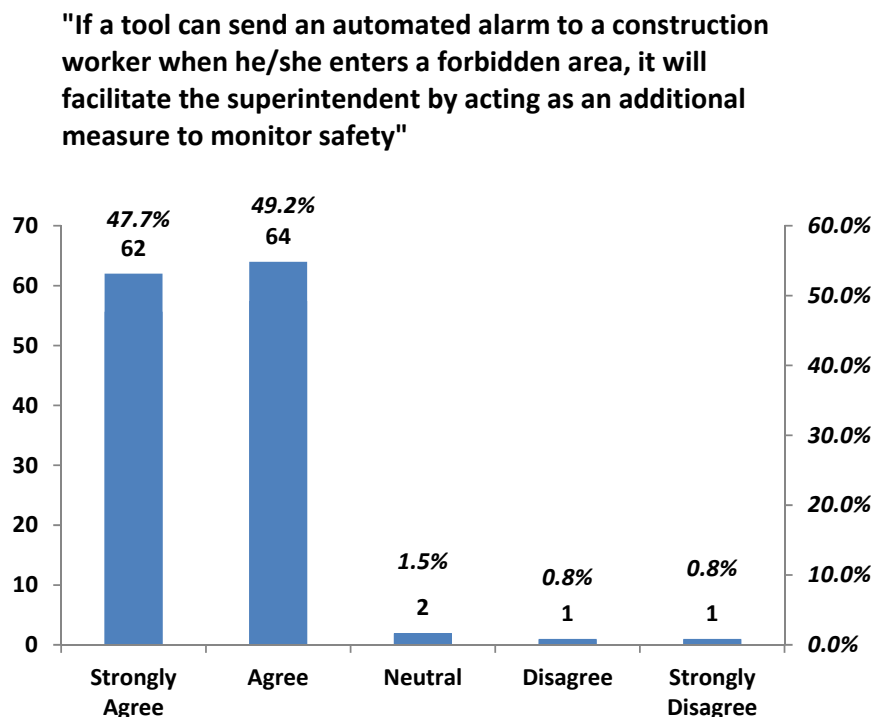


Figure 5.10: Scenario for sending automated alarms to construction workers

The responses indicate overwhelming acceptance of the proposed scenario regarding the usefulness of the proposed framework in emergency situations on a construction site. The statistical analysis for this data revealed a median value of '4.0', a mode value of '4.0' and mean value of '4.4231' for scenario 2A, as shown in Table 5.13. The standard

deviation was found to be ‘0.6454’ and the interquartile range for the data for scenario 2A was ‘1.0’.

"If a tool can send an automated alarm to a construction worker when he/she enters a forbidden area, it will facilitate the superintendent by acting as an additional measure to monitor safety"				
Median	Mode	Mean	Standard Deviation	Interquartile Range
4.0	4.0	4.4231	0.6454	1.0

Table 5.13: Central tendencies and data dispersion for scenario 2A based on all responses

The data for personnel who have over fifteen years of experience has shown that there is agreement within them also about the usefulness of scenario 2A, as shown in Table 5.14. The median value was ‘4.0’, the mode was ‘4.0’ and the mean was ‘4.3330’ with a standard deviation of ‘0.7530’. The interquartile range was ‘1.0’ within the respondents with over fifteen years of construction experience. The data presents an agreement with the proposed statement by the experienced construction personnel, as compared with the overall respondents, albeit with a slightly lower mean but with also a slightly higher standard deviation.

"If a tool can send an automated alarm to a construction worker when he/she enters a forbidden area, it will facilitate the superintendent by acting as an additional measure to monitor safety"				
Median	Mode	Mean	Standard Deviation	Interquartile Range
4.0	4.0	4.3330	0.7530	1.0

Table 5.14: Central tendencies and data dispersion for scenario 2A based on responses from personnel with more than fifteen years of construction industry experience

5.7.3 Scenario 2B – Automated Head Count

Results from the interviews with construction site superintendents indicate that in the event of an emergency situation on the construction site, an alarm is sounded and all workers present on the site are expected to drop everything and assemble at a pre-determined muster point. As workers start to assemble at the muster point, a head count process is initiated to account for everyone on the site. The superintendents, during the interview phase of this research, indicated that it is likely that the missing person(s) is/are in danger and may need assistance. Since the location of workers can be tracked at the muster point by having an RFID reader, the process of headcount can be automated. Participants were presented with the statement "A tool that can automate the head count process, in the event of an emergency situation on a construction site, will assist the superintendent" and were asked to choose an option that described their opinion towards statement, ranging from 'Strongly Agree' to 'Strongly Disagree'. The results in Figure 5.11 indicate that almost 95% of the respondents agree with this notion whereas virtually no one disagreed with this statement.

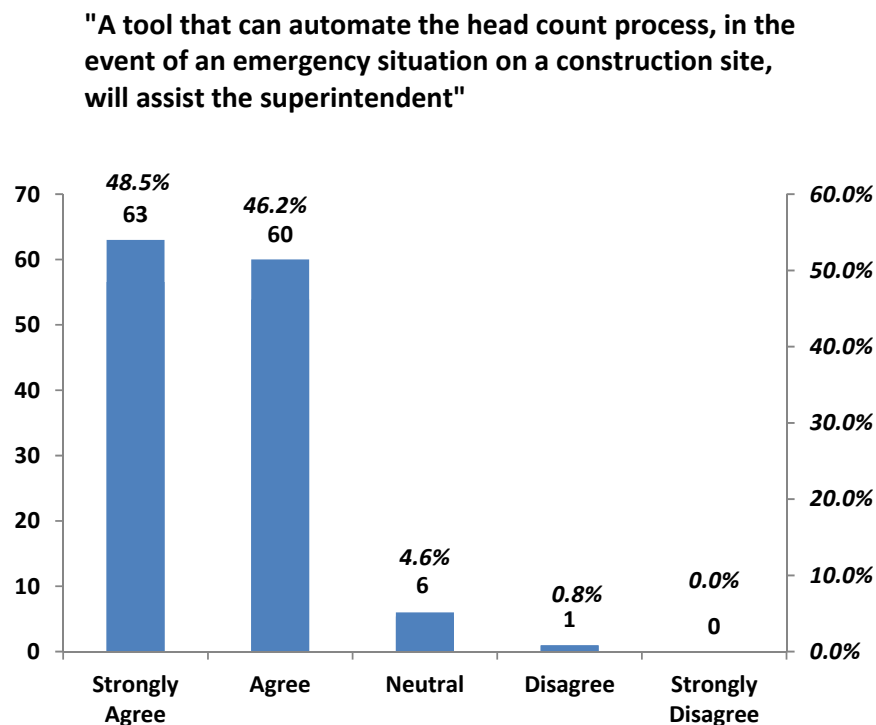


Figure 5.11: Scenario for automated headcount during an emergency situation

Statistical analysis results indicate overwhelming acceptance of the proposed scenario regarding the usefulness of the proposed framework in emergency situations on a construction site. The statistical analysis for this data revealed a median value of ‘4.0’, a mode value of ‘5.0’ and mean value of ‘4.4231’ for scenario 2B, as shown in Table 5.15. The standard deviation was found to be ‘0.6209’ and the interquartile range for the data for scenario 2B was ‘1.0’.

"A tool that can automate the head count process, in the event of an emergency situation on a construction site, will assist the superintendent"				
Median	Mode	Mean	Standard Deviation	Interquartile Range
4.0	5.0	4.4231	0.6209	1.0

Table 5.15: Central tendencies and data dispersion for scenario 2B based on all responses

The data for personnel who have over fifteen years of experience has shown that there is agreement within them about the usefulness of scenario 2B, as shown in Table 5.16. The median value was ‘4.0’, the mode was ‘4.0’ and the mean was ‘4.3330’ with a standard deviation of ‘0.6302’. The interquartile range was ‘1.0’ within the respondents with over fifteen years of construction experience. The evidence suggests that experienced construction professionals agree that the proposed tool is useful during the head count process in the event of an emergency.

"A tool that can automate the head count process, in the event of an emergency situation on a construction site, will assist the superintendent"				
Median	Mode	Mean	Standard Deviation	Interquartile Range
4.0	4.0	4.3330	0.6302	1.0

Table 5.16: Central tendencies and data dispersion for scenario 2B based on responses from personnel with more than fifteen years of construction industry experience

5.7.4 Summary of ‘Emergency & Critical Situations’ Scenario

Encouraging comments about scenario 2 to track workers during emergency or critical situations using the proposed framework are presented in Table 5.17. Positive feedback from the statistical data was reflected in the comments as well, as depicted by the comment “...also being on a project site where forbidden zones typically mean radioactive hot spots, it would be very intuitive to receive an alarm should a worker get “too close” to a hot spot”. The codes indicate that the proposed system would be useful in nuclear power plants, healthcare projects and tunnel construction. The comments also indicate it would be better than using hardhat stickers and passive tag based systems.

Positive Feedback	
<ul style="list-style-type: none"> ○ An alert to the workers if they get close to a radioactive hot spot would be useful ○ An RFID solution would greatly simplify the monitoring process for the safety officers ○ Can see this tool being helpful in healthcare project ○ Could be used in tunnel construction 	<ul style="list-style-type: none"> ○ It would be a better way than hard-hat stickers ○ It would be better than a passive tag system with fixed locations at entry and exit points as these points change in a project ○ This could be very useful for construction at an active nuclear power plant where radioactivity is present

Table 5.17: Codes derived from comments about scenario 2 leaning towards positive feedback to tracking workers during emergency / critical situations

Disagreements, suggestions and other thoughts from the comments section for scenario 2 are presented in Table 5.18. Respondents cautioned that a superintendent must not rely too much on technology for monitoring safety, as evidenced by the comment *“Technology should supplement and not take the place of an actual head count”*. Respondents also cautioned that all workers must be tagged, that there are too many people coming and leaving the site, it is difficult to get an accurate count, that workers may sometimes not wear their tags and that there are many variables to consider. The issues pointed out by these respondents are indeed valid statements and must be examined further. However issues related to implementation on an actual construction site are deemed beyond the scope of the study. There is no clear way to identify how much technology is too much or how much is too little. This issue again is beyond the scope of this study. The proposed method of tracking is for buildings and not heavy civil construction projects such as roads. The use of GPS based systems would be better suited for road construction projects. The tags don’t have to be attached to the hard hat and instead could be placed as an ID card.

Cautious Approach	
<ul style="list-style-type: none"> ○ A superintendent should be cautious not to rely too heavily on an automated process during a safety emergency ○ All workers will have to be tagged for this to work ○ Difficult to get an accurate count ○ Hard hat may not be the best place to tag a worker 	<ul style="list-style-type: none"> ○ Many variables to consider ○ No benefits for heavy civil construction ○ Technology should supplement and not take the place of an actual head count ○ Too many people coming and going on the site ○ Workers sometimes don't wear hard hats

Table 5.18: Codes derived from comments about scenario 2 leaning towards a cautious approach to tracking workers during emergency / critical situations

The statistical analysis suggests that well over 90% of the construction professionals agreed that the proposed tool would be useful to the construction superintendent in the event of emergency or critical situation, as seen in Table 5.19. Therefore the scenario to track workers on the construction site during emergency or critical situations may be considered as validated.

Statement	Agree	Neutral	Disagree
Scenario 2	97%	2%	0%
Scenario 2A	97%	1.5%	1.5%
Scenario 2B	94%	5%	1%

Table 5.19: Snapshot view of data showing levels of agreement, neutrality or disagreement regarding scenario 2

5.8 Tracking Construction Workers by Zones

The idea of dividing the construction site into various zones is not an unusual practice on the construction site (Teizer et al., 2007). Teizer et al(2007) proposed the system of creating safe and unsafe zones to track resources on a construction site using 3D modelling. Interviews with construction superintendents revealed that one of the methods

used by superintendents is to use special hard-hat stickers to identify which workers are supposed to be working in a specific area. This is a visual indicator for the superintendent, foremen and fellow workers to act accordingly when an unauthorised person enters a construction zone. The proposed RFID & BIM combination would allow the construction superintendent to monitor the entire site to quickly spot people that might have entered an unauthorised/dangerous zone. In the third scenario, the respondents were presented with the idea of tracking construction workers based on splitting the construction site into various pre-determined zones, based on type of work being performed. An illustration and the description shown to the survey respondents of the proposed system are presented in Figure 5.12.

“A scenario in which workers can be tracked by colour coded scheme, based on whether or not they are in the correct zone is proposed. Instead of the superintendent looking at all the workers and identifying if they are in the correct place, this process would split the site into various zones and highlight anyone that is not in the correct zone, based on a previously decided scheme.”

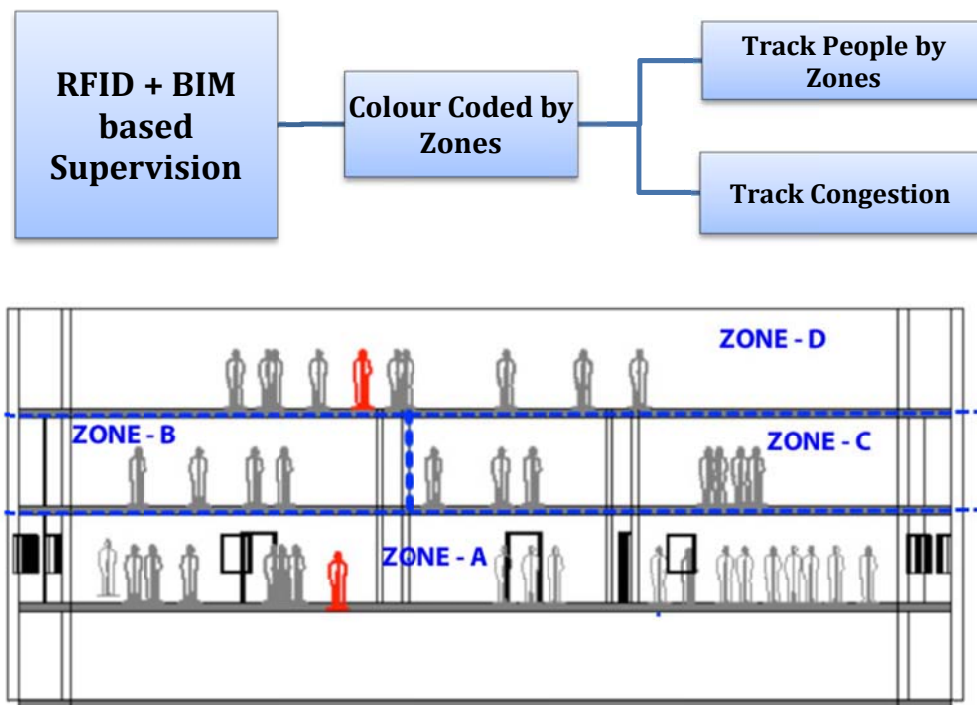


Figure 5.12: Tracking construction workers by zone within the site

5.8.1 Scenario 3 – Tracking Workers by Zone

Participants were presented with the statement "A construction site may be divided into zones to allow the superintendent to track movement of workers within each zone, as shown in the figure above" and asked to choose an option that described their opinion towards statement, ranging from 'Strongly Agree' to 'Strongly Disagree'. 80% of the respondents agreed with this statement whereas 3% disagreed and approximately 17% of the respondents were neutral in their response to this question, as shown in Figure 5.13.

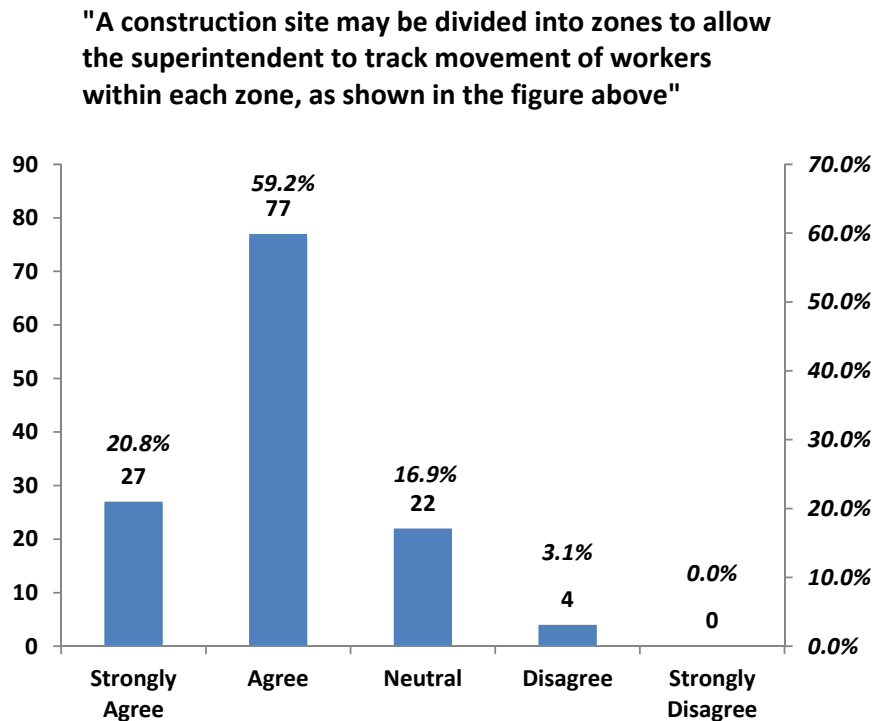


Figure 5.13: Tracking construction workers by zone within the site

Statistics presented in Table 5.20 indicate that the majority of the respondents agree that it is possible to divide the construction site into zones and track workers using the proposed scenario to monitor the movement of workers within the construction zone. The statistical analysis for this data revealed a median value of '4.0', a mode value of '4.0' and mean value of '3.9769' for scenario 3, as shown in Table 5.20. The standard deviation was found to be '0.7095' and the interquartile range for the data for scenario 3 was '0.0'.

"A tool that can automate the head count process, in the event of an emergency situation on a construction site, will assist the superintendent"				
Median	Mode	Mean	Standard Deviation	Interquartile Range
4.0	4.0	3.9769	0.7095	0.0

Table 5.20: Central tendencies and data dispersion for scenario 3 based on all responses

The data for personnel who have over fifteen years of experience has shown that there is agreement within them about the usefulness of scenario 3, as shown in Table 5.21. The median value was '4.0', the mode was '4.0' and the mean was '3.8750' with a standard deviation of '0.6058'. The interquartile range was '0.0' within the respondents with over fifteen years of construction experience. The data suggests that experienced construction professionals agree that the proposed tool is useful during the head count process in the event of an emergency.

"A tool that can automate the head count process, in the event of an emergency situation on a construction site, will assist the superintendent"				
Median	Mode	Mean	Standard Deviation	Interquartile Range
4.0	4.0	3.8750	0.6058	0.0

Table 5.21: Central tendencies and data dispersion for scenario 3 based on responses from personnel with more than fifteen years of construction industry experience

5.8.2 Scenario 3A – Tracking Workers by Authorized Zones

Participants were presented with the statement *"A tool that can highlight, in real-time, construction workers when they enter an unauthorised zone on the site, will facilitate the*

superintendent by acting as additional means to monitor site safety" and asked to choose an option that described their opinion towards statement, ranging from 'Strongly Agree' to 'Strongly Disagree'. The results in Figure 5.14 indicate that over 86% of the respondents agree with this statement and only two respondents disagreed with it. Approximately 12% of the respondents gave a neutral response to the statement.

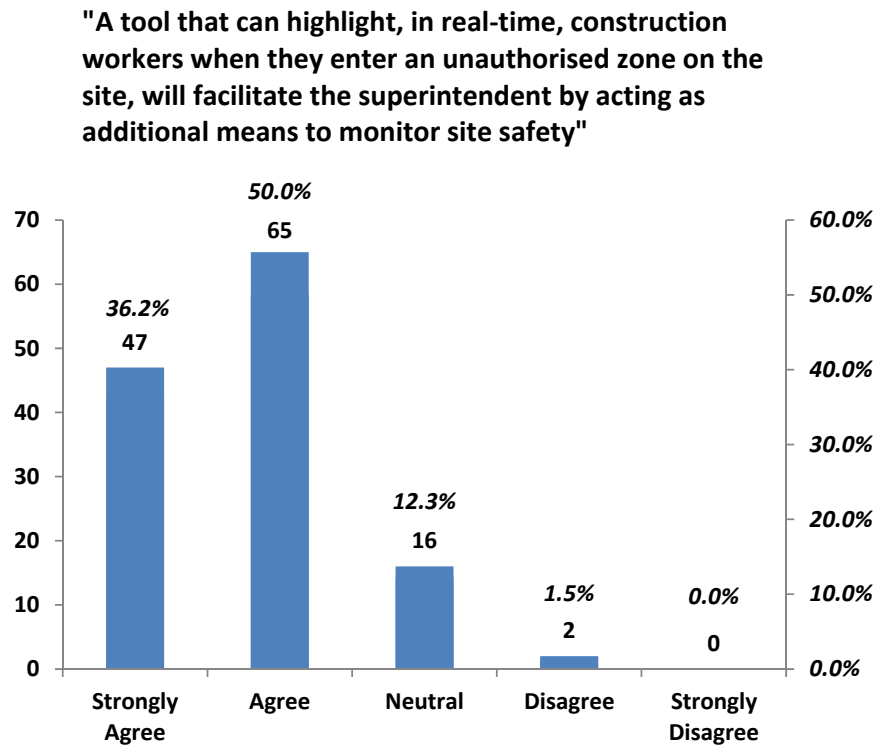


Figure 5.14: Highlight construction workers when they enter an unauthorised zone

There is general acceptance among respondents that the superintendent would be enabled by being able to view construction workers when they enter an unauthorised zone, as evidenced by the comment *"I believe this would facilitate the subcontractors personnel management so they could then better report progress to the superintendent"*. The statistical analysis for this data revealed a median value of '4.0', a mode value of '4.0' and mean value of '4.2077' for scenario 3A, as shown in Table 5.22. The standard deviation was found to be '0.7120' and the interquartile range for the data for scenario 3A was '1.0'.

"A tool that can automate the head count process, in the event of an emergency situation on a construction site, will assist the superintendent"				
Median	Mode	Mean	Standard Deviation	Interquartile Range
4.0	4.0	4.2077	0.7120	1.0

Table 5.22: Central tendencies and data dispersion for scenario 3A based on all responses

The data for personnel who have over fifteen years of experience has shown that there is agreement within them about the usefulness of scenario 3A, as shown in Table 5.23. The median value was ‘4.0’, the mode was ‘4.0’ and the mean was ‘4.0630’ with a standard deviation of ‘0.7550’. The interquartile range was ‘1.0’ within the respondents with over fifteen years of construction experience. The evidence suggests that experienced construction professionals agree that the proposed tool is useful during the head count process in the event of an emergency.

"A tool that can automate the head count process, in the event of an emergency situation on a construction site, will assist the superintendent"				
Median	Mode	Mean	Standard Deviation	Interquartile Range
4.0	4.0	4.0630	0.7550	1.0

Table 5.23: Central tendencies and data dispersion for scenario 3A based on responses from personnel with more than fifteen years of construction industry experience

5.8.3 Scenario 3B – Tracking Congestion on Construction Sites

Respondents to the survey were asked to rate the statement "*The proposed tool will allow the superintendent, in real-time, to identify congested areas within the site*", depicting their agreement on a range of ‘Strongly Agree’ to ‘Strongly Disagree’. 85% of the

respondents agreed that the proposed tool would facilitate the construction superintendent to identify congested areas, as shown in Figure 5.15. Only 3% of the respondents disagreed with the statement while approximately 12% of the respondents gave a neutral response.

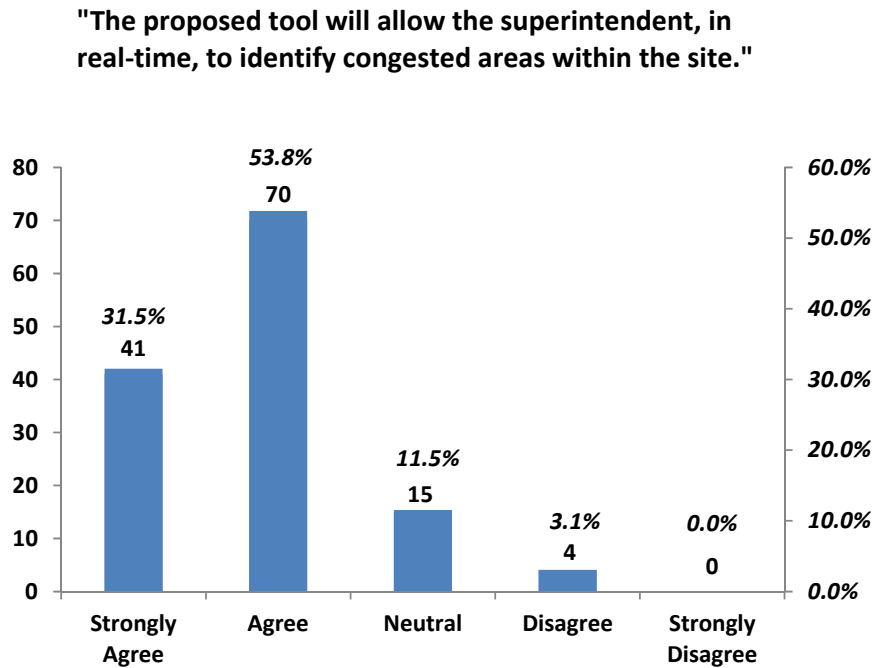


Figure 5.15: Tracking congestion within the construction site

There is high degree of acceptance among respondents that the superintendent would be enabled by being able to view construction workers identify congested areas, as evidenced by the comment *"Identifying congested areas for the purpose of alleviating congestion by creating alternate means of egress could equal higher production levels and safer work areas"*. The statistical analysis for this data revealed a median value of '4.0', a mode value of '4.0' and mean value of '4.1385' for scenario 3B, as shown in Table 5.24. The standard deviation was found to be '0.7340' and the interquartile range for the data for scenario 3B was '1.0'.

"The proposed tool will allow the superintendent, in real-time, to identify congested areas within the site"				
Median	Mode	Mean	Standard Deviation	Interquartile Range
4.0	4.0	4.1385	0.7340	1.0

Table 5.24: Central tendencies and data dispersion for scenario 3B based on all responses

The data for personnel who have over fifteen years of experience has shown that there is agreement within them about the usefulness of scenario 3B, as shown in Table 5.25. The median value was '4.0', the mode was '4.0' and the mean was '3.9380' with a standard deviation of '0.7830'. The interquartile range was '0.75' within the respondents with over fifteen years of construction experience. The evidence suggests that experienced construction professionals agree that the proposed tool is useful identify congested areas.

"The proposed tool will allow the superintendent, in real-time, to identify congested areas within the site"				
Median	Mode	Mean	Standard Deviation	Interquartile Range
4.0	4.0	3.9380	0.7830	0.75

Table 5.25: Central tendencies and data dispersion for scenario 3B based on responses from personnel with more than fifteen years of construction industry experience

5.8.4 Summary of 'Tracking Workers by Zones' Scenario

Codes derived from comments that provided a positive feedback for scenario 3 are presented in Table 5.26. The comments suggested that the proposed tool could be used to track congestion, improve productivity and safety within the construction site. The comments also the proposed tool could be used by subcontractors as evidenced by the comment *"I believe this would facilitate the subcontractors personnel management so they could then better report progress to the superintendent"*.

Positive Feedback	
<ul style="list-style-type: none"> ○ Could be useful to track congested areas 	<ul style="list-style-type: none"> ○ May help improve productivity and safety by creating alternate egress for congested areas ○ This could be used by subcontractors also for personnel management

Table 5.26: Codes derived from comments about scenario 3 leaning towards positive feedback to tracking workers by zones within the site

Codes derived from comments suggesting a cautious approach or disagreements are presented in Table 5.27. Comments suggest that not many construction sites need to be divided into zones, that workers have to move through various zones and that the zones on a construction site are constantly changing, as evidenced by the comment “*On most sites, the "zones" are constantly changing as the project progresses*”.

Cautious Approach	
<ul style="list-style-type: none"> ○ Not many jobs need to be divided into zones ○ I don't see this as a useful tool 	<ul style="list-style-type: none"> ○ Workers sometimes have to move through different zones ○ Zones are constantly changing as the project progresses

Table 5.27: Codes derived from comments about scenario 3 leaning towards a cautious approach to tracking workers by zones within the site

The data for scenario 3, to track workers by zones, indicates an overwhelming agreement amongst construction professionals that this would enable the construction site superintendent, as evidenced by the data presented in Table 5.28. 80% or more of the respondents agreed with the statements presented in this scenario. Therefore the scenario to track workers by dividing the construction site into zones may be considered as validated.

Statement	Agree	Neutral	Disagree
Scenario 3	80%	17%	3%
Scenario 3A	86%	12%	2%
Scenario 3B	85%	12%	3%

Table 5.28: Snapshot view of data showing levels of agreement, neutrality or disagreement regarding scenario to track workers by zone within the construction site

5.9 Remote Monitoring

The size, complexity and scale of large construction sites are some of the reasons managers have looked to remote monitoring of construction sites by using electronic means (Zhong et al., 2009). Interviews with construction superintendents also revealed that on a large construction site it is not possible for the superintendent to know where everyone is located within the construction site. Superintendents also revealed that part of their normal responsibilities include attending offsite meetings with owners and other key stakeholders. In the fourth scenario, respondents were presented with the description and the associated illustration presented in Figure 5.16, about using the proposed tool to monitor activities remotely by either the superintendent or other relevant parties. Interviews with construction superintendents revealed that an important aspect of their responsibilities include attending various meetings regarding the construction process. The proposed tool can be used by the superintendent to remotely keep an eye on the site.

“The proposed solution can be used for remote management and provide some measure of oversight for the superintendent that cannot go to all areas of the site. This can also be used for remotely monitoring the site from the home office, if necessary. This solution can be used by the foreman, safety officers and others.”

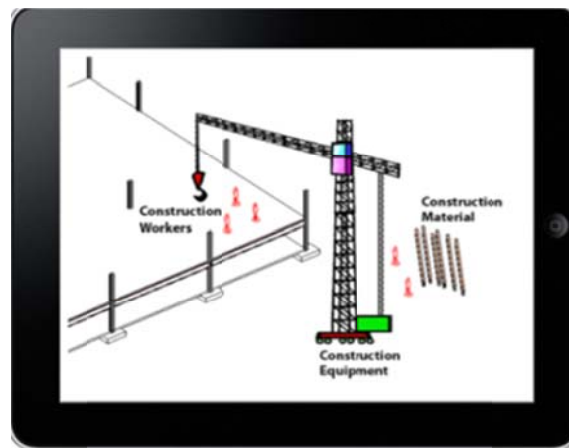
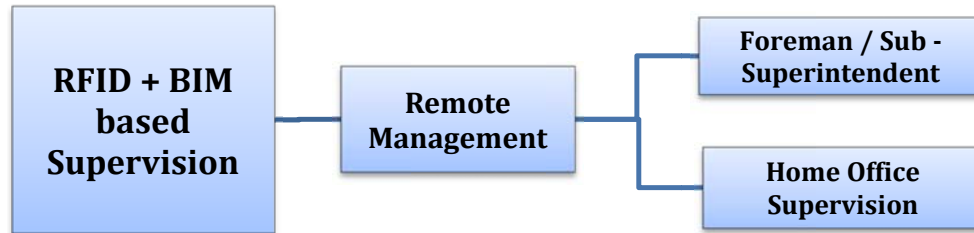


Figure 5.16: Remote Management Using RFID & BIM Solution

5.9.1 Scenario 4 – Remote Monitoring by the Construction Superintendent

Participants were presented with the statement *"If a superintendent is unable to be physically on the site (e.g.: attending a meeting), they will be facilitated by using the proposed tool to remotely monitor the site in real-time"* and asked to choose an option that described their opinion towards statement, ranging from ‘Strongly Agree’ to ‘Strongly Disagree’. 80% of the respondents agreed with the statement whereas only 4% of the respondents disagreed with it while approximately 15% of the respondents gave a neutral response, as shown in Figure 5.17.

"If a superintendent is unable to physically be on the site (E.g.: attending a meeting), he/she will be facilitated by using the proposed tool to remotely monitor the site in real time"

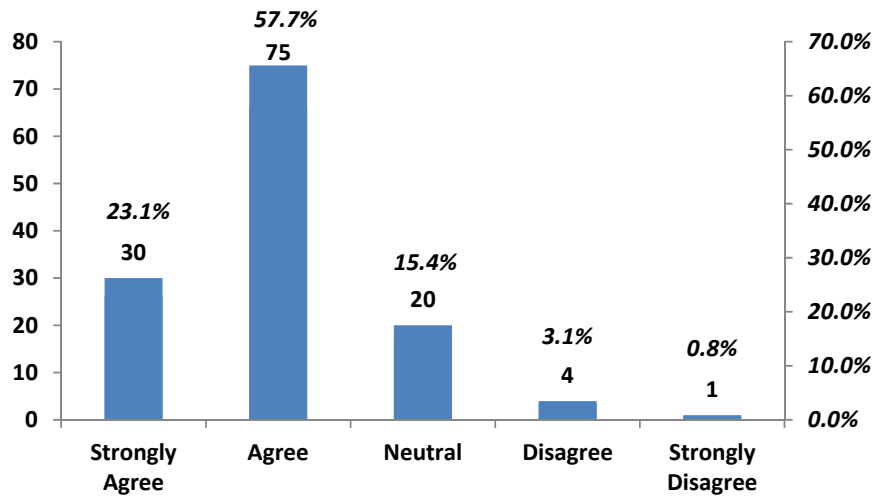


Figure 5.17: Remote Management Using RFID & BIM Solution

There is high level of acceptance among the respondents that the superintendent would be enabled by being able to use the proposed tool to remotely monitor the site in real time but the comment also urged caution as evidenced by the comment *"Nothing replaces a superintendent actually being present on the jobsite"*. The statistical analysis for this data revealed a median value of '4.0', a mode value of '4.0' and mean value of '3.9923' for scenario 4, as shown in Table 5.29. The standard deviation was found to be '0.7625' and the interquartile range for the data for scenario 4 was '0.0'.

"If a superintendent is unable to physically be on the site (E.g.: attending a meeting), he/she will be facilitated by using the proposed tool to remotely monitor the site in real-time"				
Median	Mode	Mean	Standard Deviation	Interquartile Range
4.0	4.0	3.9923	0.7625	0.0

Table 5.29: Central tendencies and data dispersion for scenario 4 based on all responses

The data for personnel who have over fifteen years of experience has shown that there is agreement within them about the usefulness of scenario 4, as shown in Table 5.30. The median value was '4.0', the mode was '4.0' and the mean was '3.9580' with a standard deviation of '0.7430'. The interquartile range was '0.0' within the respondents with over fifteen years of construction experience. The evidence suggests that experienced construction professionals agree that the proposed tool is useful when the superintendent is physically unable to be on site.

"If a superintendent is unable to physically be on the site (E.g.: attending a meeting), he/she will be facilitated by using the proposed tool to remotely monitor the site in real-time"				
Median	Mode	Mean	Standard Deviation	Interquartile Range
4.0	4.0	3.9580	0.7430	0.0

Table 5.30: Central tendencies and data dispersion for scenario 4 based on responses from personnel with more than fifteen years of construction industry experience

5.9.2 Scenario 4A – Remote Monitoring by the Foremen and Subcontractor Superintendents

Participants were presented with the statement *"Foremen and subcontractor superintendents will also be able to use the proposed tool to monitor the movement of their respective crew members within the site"* and asked to choose an option that described their opinion towards the statement, ranging from 'Strongly Agree' to 'Strongly Disagree'. The results presented in Figure 5.18 indicate that more than 85% of the respondents agreed with the statement. About 3% of the respondents disagreed with the statement while approximately 12% of the respondents gave a neutral response.

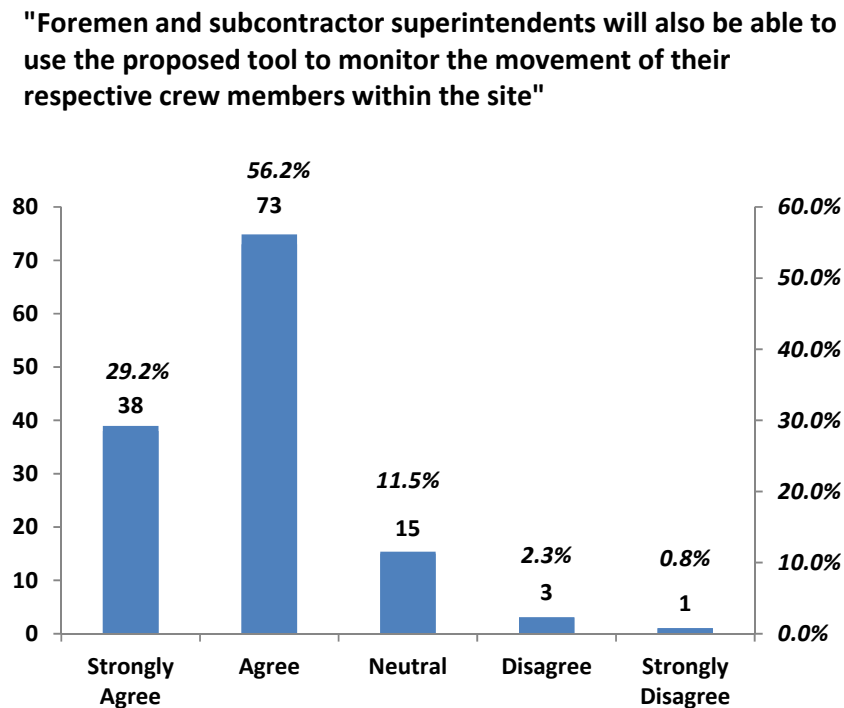


Figure 5.18: Remote Management Using RFID & BIM Solution

A majority of the respondents agree that the trade superintendents and foremen would be enabled by using the proposed tool to monitor their crew on the site in real time but comments suggested a more cautious approach, as evidenced by the comment *"I think this tool could assist the field staff but shouldn't take the place of their presence on the job"*. The statistical analysis for this data revealed a median value of '4.0', a mode value

of '4.0' and mean value of '4.1077' for scenario 4A, as shown in Table 5.31. The standard deviation was found to be '0.7496' and the interquartile range for the data for scenario 4A was '1.0'.

"Foremen and subcontractor superintendents will also be able to use the proposed tool to monitor the movement of their respective crew members within the site"				
Median	Mode	Mean	Standard Deviation	Interquartile Range
4.0	4.0	4.1077	0.7496	1.0

Table 5.31: Central tendencies and data dispersion for scenario 4A based on all responses

The data for personnel who have over fifteen years of experience has shown that there is agreement within them about the usefulness of scenario 4A, as shown in Table 5.32. The median value was '4.0', the mode was '4.0' and the mean was '4.0630' with a standard deviation of '0.7270'. The interquartile range was '1.0' within the respondents with over fifteen years of construction experience. The evidence suggests that experienced construction professionals agree that the proposed tool would enable trade contractor superintendents and construction crew foremen.

"Foremen and subcontractor superintendents will also be able to use the proposed tool to monitor the movement of their respective crew members within the site"				
Median	Mode	Mean	Standard Deviation	Interquartile Range
4.0	4.0	4.0630	0.7270	1.0

Table 5.32: Central tendencies and data dispersion for scenario 4A based on responses from personnel with more than fifteen years of construction industry experience

5.9.3 Scenario 4B – Remote Monitoring by Home Office Personnel

Participants were presented with the statement *"The proposed tool will facilitate home office personnel to monitor the progress of construction on the site"* and asked to choose an option that described their opinion towards the statement, ranging from 'Strongly Agree' to 'Strongly Disagree'. The responses indicate that over 58% of the respondents agreed that home office personnel could use the proposed tool to monitor the progress of construction, while 16% of the respondents disagreed with the statement and 24% did not feel strongly either way, based on the responses presented in Figure 5.19.

"The proposed tool will facilitate home office personnel to monitor the progress of construction on the site"

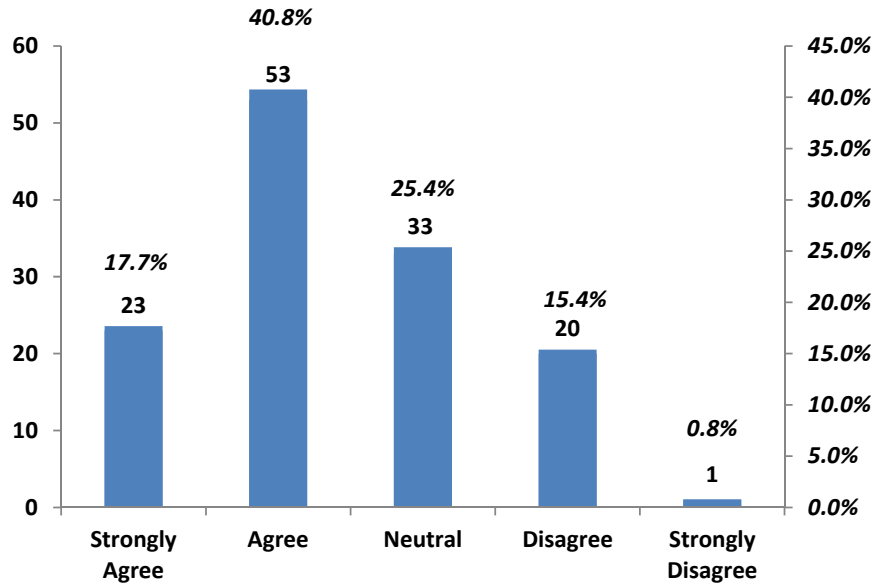


Figure 5.19: Remote Management Using RFID & BIM Solution

While the data revealed that a majority of the respondents agreed with the statement that home office personnel could use the information by remotely viewing the location of workers, the comments revealed a more cautious approach as evidenced by the comment “*Worker location and number may not provide an accurate depiction of overall progress*”. The statistical analysis for this data revealed a median value of ‘4.0’, a mode value of ‘4.0’ and mean value of ‘3.5923’ for scenario 4B, as shown in Table 5.33. The standard deviation was found to be ‘0.9780’ and the interquartile range for the data for scenario 4B was ‘1.0’.

"The proposed tool will facilitate home office personnel to monitor the progress of construction on the site"				
Median	Mode	Mean	Standard Deviation	Interquartile Range
4.0	4.0	3.5923	0.9780	1.0

Table 5.33: Central tendencies and data dispersion for scenario 4B based on all responses

The data for personnel who have over fifteen years of experience has shown that there is agreement within them about the usefulness of scenario 4B, as shown in Table 5.34. The median value was '3.5', the mode was '4.0' and the mean was '3.2920' with a standard deviation of '0.9670'. The interquartile range was '1.75' within the respondents with over fifteen years of construction experience. A closer examination of the evidence suggested that 50% of the experienced construction professionals agreed, while 25% disagreed and another 25% chose a neutral stance to the statement that the proposed tool to be useful for home office personnel. This further explains the high value for the interquartile range.

"The proposed tool will facilitate home office personnel to monitor the progress of construction on the site"				
Median	Mode	Mean	Standard Deviation	Interquartile Range
3.5	4.0	3.2920	0.9670	1.75

Table 5.34: Central tendencies and data dispersion for scenario 4B based on responses from personnel with more than fifteen years of construction industry experience

5.9.4 Summary of ‘Remote Monitoring’ Scenario

Codes derived from comments that agreed with the proposed framework for using it to remotely manage the construction site are presented in Table 5.35. Comments indicated that it could be useful for travelling office managers, useful for payroll verification purposes, useful for project managers and would allow the movement of workers be monitored, as evidenced by the comment “*Seems like the system would be more useful for payroll verification purposes*”.

Positive Feedback	
<ul style="list-style-type: none"> ○ Could be used by traveling office managers ○ Could be useful for payroll verification purposes 	<ul style="list-style-type: none"> ○ Could be useful for project managers ○ It would be great tool ○ Will allow movement of crews to be monitored

Table 5.35: Codes derived from comments about scenario 4 leaning towards positive feedback to using the framework for remote management

Codes derived from comments suggesting a cautious approach to using the proposed framework for remote management are presented in Table 5.36. Comments suggest that superintendents and foremen must personally verify safety and productivity as evidenced by the comment “*This tool should not be used as a substitute for the superintendent taking the time to walk his job in order to inspect quality, safety and progress first hand*”. Comments also indicate the location of workers and the number of workers at a particular location does not indicate the amount of work being done, as evidenced by the comment “*This tool will only allow the movement of crews to be monitored, not progress of work*”.

Cautious Approach	
<ul style="list-style-type: none"> ○ Crew size alone does not indicate productivity ○ Foremen would need mobile devices to use this tool ○ Foremen and superintendent must personally supervise work 	<ul style="list-style-type: none"> ○ Location of workers does not indicate production ○ Superintendent must personally verify productivity ○ Superintendents must personally supervise safety

Table 5.36: Codes derived from comments about scenario 4 leaning towards a cautious approach to using the framework to remotely manage the site

The data indicate more than 80% of the respondents agree that the superintendent can use the proposed tool when they are unable to physically monitor the construction site and that the proposed tool would be useful for subcontractor superintendents and foremen, as shown in Table 5.37. A majority also agree that the proposed tool would be useful for home office personnel. By ignoring the 25% that chose a neutral stance for scenario 4B, more than three times as many respondents agreed versus those that disagreed with the proposed statement. Based on the data presented in Table 5.37, the scenario 4, to use the proposed tool for remote management may be considered validated.

Statement	Agree	Neutral	Disagree
Scenario 4	81%	15%	4%
Scenario 4A	85%	12%	3%
Scenario 4B	59%	25%	16%

Table 5.37: Snapshot view of data showing levels of agreement, neutrality or disagreement regarding scenario 4

5.10 Overall Framework

In the final section of the survey, respondents were asked to rate the overall framework based on the four scenarios presented in the previous sections. The illustration presented and the associated descriptions are shown in Figure 5.20.

“A combination of BIM & RFID technologies is proposed to track the movement of construction workers within a site. The conceptual framework has four scenarios by which safety on construction sites may be monitored by site superintendents, as shown below.”

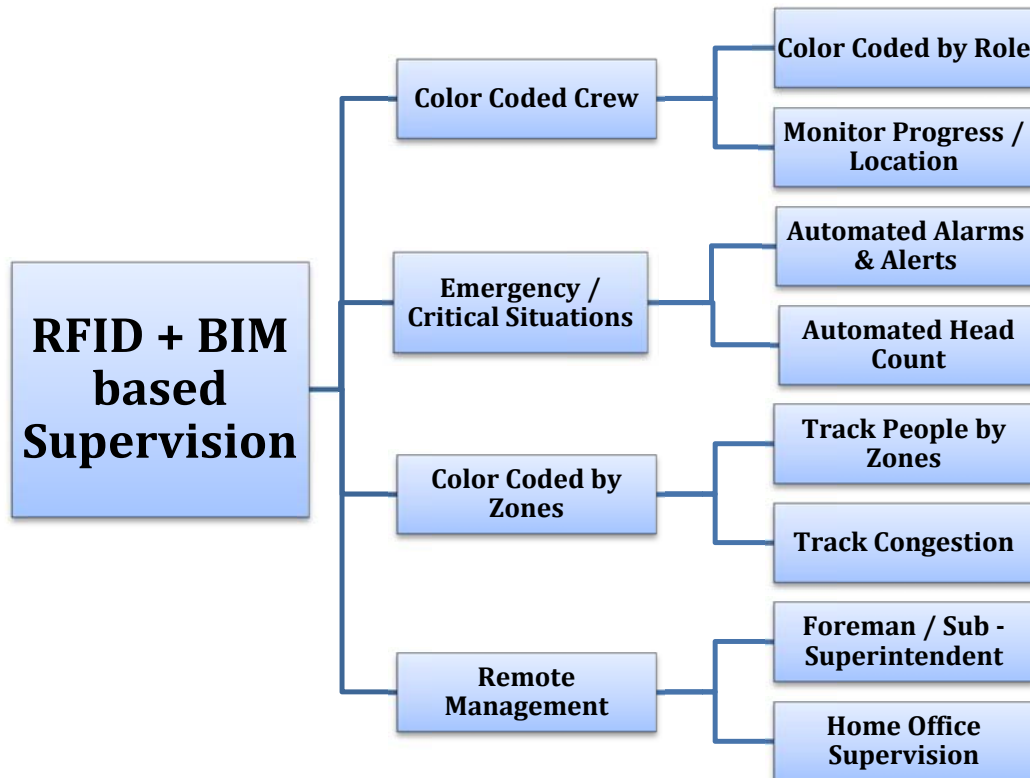


Figure 5.20: Framework for Monitoring using RFID & BIM technologies

Participants were presented with the statement *"The proposed tool is an additional means to facilitate superintendents to monitor the health & safety of construction workers on a site"* and asked to choose an option that described their opinion towards the statement, ranging from 'Strongly Agree' to 'Strongly Disagree'. Over 80% of the respondents agreed with the concept of using the proposed tool as an additional means to enable the construction superintendent to monitor the health & safety of workers on a construction site. Only 3% of the respondents disagreed with the statement, while 16% of the respondents gave a neutral response.

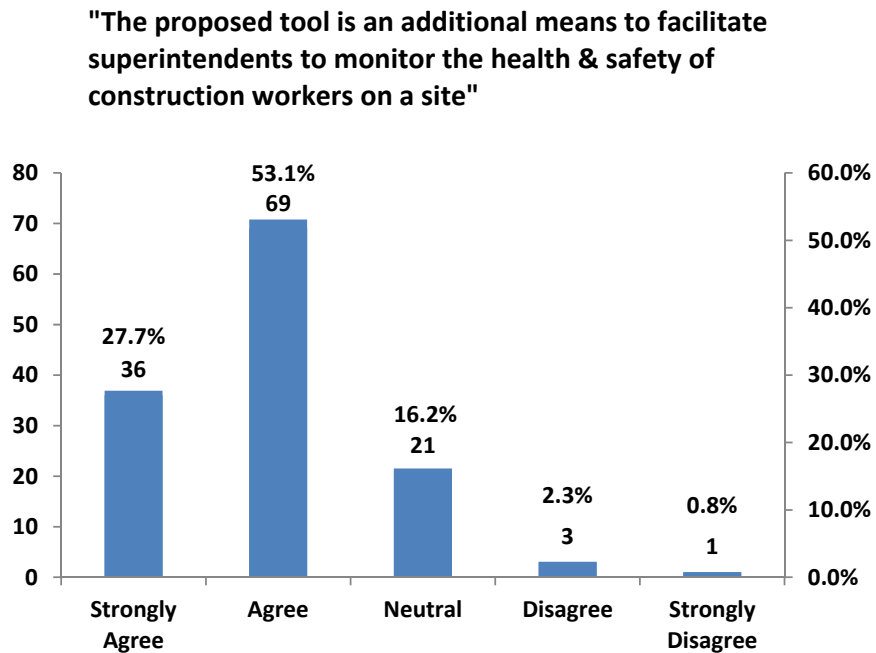


Figure 5.21: Framework validation for health & safety monitoring using the proposed tool

The statistical analysis for the overall framework revealed a median value of '4.0', a mode value of '4.0' and mean value of '4.0462', as shown in Table 5.38. The standard deviation was found to be '0.7762' and the interquartile range for the data for the overall framework was '1.0'. This reveals a high level of agreement among the respondents about the usefulness of the proposed framework to monitor the health and safety of construction workers.

"The proposed tool is an additional means to facilitate superintendents to monitor the health & safety of construction workers on a site"				
Median	Mode	Mean	Standard Deviation	Interquartile Range
4.0	4.0	4.0462	0.7762	1.0

Table 5.38: Central tendencies and data dispersion for scenario 4B based on all responses

The data for personnel who have over fifteen years of experience has shown that there is agreement within them about the usefulness of the overall framework, as shown in Table 5.39. The median value was '4.0', the mode was '4.0' and the mean was '3.9790' with a standard deviation of '0.8630'. The interquartile range was '1.0' within the respondents with over fifteen years of construction experience. The evidence suggests that experienced construction professionals agree that the proposed framework is a useful tool to monitor the health and safety of construction workers on the construction site.

"The proposed tool is an additional means to facilitate superintendents to monitor the health & safety of construction workers on a site"				
Median	Mode	Mean	Standard Deviation	Interquartile Range
4.0	4.0	3.9790	0.8630	1.0

Table 5.39: Central tendencies and data dispersion for scenario 4B based on responses from personnel with more than fifteen years of construction industry experience

Fifty-eight respondents of the survey commented on the overall framework. Many of the comments were positive, to varying degrees, about the proposed framework for tracking

movement of construction workers, as shown in Table 5.40. Some of the themes that emerged from the comments include: useful on large projects, useful during emergency situations, useful as an additional tool, useful when there are many people on the construction site, useful in an critical construction processes such as blasting or demolition. Several comments indicated that this would be a useful tool during emergency situations. Comments suggested that the tool could be useful for more than monitoring health and safety on a construction site. The word “great” was used nineteen times in the comments, the word “benefit/beneficial” was used twelve times, the word “emergency” was used nine times. The comments presented in Table 5.40 suggest a high approval rating among the respondents of the survey towards the framework to monitor the movement of construction workers using RFID and BIM.

Positive Feedback	
<ul style="list-style-type: none"> ○ A lot of potential ○ Constant monitoring is always required and this would make monitoring easier and efficient ○ Cool ideas! ○ Could be a useful tool in an emergency situation ○ Could be useful for head count ○ Could be useful for payroll verification purposes ○ Could be useful for tracking people by zones ○ Could be useful on many project types ○ Could be utilized to track tools ○ Great concept ○ Could be a useful tool in an emergency situation ○ Great potential to alert people when they enter a hazardous zone on active nuclear power plants ○ Great tool to monitor project when superintendent cannot be everywhere at once ○ Huge value in maintaining a secure site ○ I believe that this system provides a great tool for a superintendent as it pertains to safety ○ I can see several applications of this being very useful ○ I can see this as a solution to deter theft ○ I can see this system being of value on larger industrial projects or renovations to operating facilities ○ I like this concept ○ I see great value in locating manpower especially during emergency situations ○ I think this is a great idea ○ I think this is a really sharp tool ○ I think this is a tremendously useful tool ○ I think this would be a good thing on 	<ul style="list-style-type: none"> ○ It is useful for construction companies and owners as well ○ It may be useful for a project manager ○ It offers a good way to make sure everyone is where they need to be ○ It will be an amazing asset to the construction industry ○ Logic presented is sound for tracking movement of workers ○ Most useful for restricted areas and unauthorized personnel ○ Must ensure that everyone is wearing their RFID tag ○ Neat idea! ○ Overall it seems like a very effective idea ○ Safety would be the biggest benefit ○ Seems like an excellent use of the technology with a variety of implementation areas ○ Superintendent can see if workers in a wrong location ○ The construction industry is always looking for ways to improve safety and this would be great idea ○ The proposed tool has the potential to provide on and off-site monitoring of production and safety on the jobsite ○ There are numerous beneficial applications of this idea ○ This could be used on any type of construction project ○ This could be useful to ensure quality control ○ This is a great idea to allow the supervision on the jobsite or home office additional resources to use to track manpower, productivity and safety management ○ This is a very thought provoking topic ○ This is intriguing technology ○ This tool can be useful for more than safety monitoring ○ This will provide a safe work environment

Positive Feedback	
<p>large jobs with a lot of workers on site</p> <ul style="list-style-type: none"> ○ I think you have an excellent idea here ○ I truly think this will be a great tool in safety and overall jobsite control ○ I'd love to have someone get me more details about implementing this ○ I'd love to hear more about this ○ If coupled with 4D scheduling, could be useful to track progress ○ If implemented correctly, this solution of combining RFID and BIM appears to be a positive improvement to the jobsite ○ If this is used appropriately it would be a benefit to the construction process for safety and productivity ○ In theory it is a good idea ○ It could be effective as an additional means 	<ul style="list-style-type: none"> ○ This would be a tool in the safety monitoring process ○ Useful for dangerous activities ○ Useful for jobsites with restricted areas ○ Useful to monitor worker location as it relates to safety ○ Useful to track visitors ○ Will allow movement of crews to be monitored ○ Will allow superintendents dealing with an issue within the project to have oversight of the entire project ○ Will allow superintendents to check if required number of workers are present ○ Will help on congested projects ○ Would allow the superintendent to see the big picture

Table 5.40: Codes derived from comments leaning towards positive feedback about the framework to monitor the health and safety of construction workers using RFID and BIM

Several comments suggesting a cautious approach were also identified and presented in Table 5.41. Some of the respondents were concerned that superintendents might become too reliant on this technology and not physically inspect the site as many times as they might have in the absence of the proposed technology. Several questions were raised about the technological, economical, logistical issues associated with implementation of the proposed framework. Some of the comments indicated that they were positive about the framework but were sceptical that the technology can actually be used in a practical situation in a construction site. The comment “*I honestly don't see a super using it unless it is an emergency or dangerous situation*” best describes the pessimistic respondents thoughts about the framework.

Cautious Approach	
<ul style="list-style-type: none"> ○ Construction workers do not like to be tagged ○ Cost of implementing must be studied ○ First hand observation by the superintendent cannot be replaced ○ Foremen and superintendent must personally supervise work ○ Hard hat may not be the best place to tag a worker ○ I honestly don't see a super using it unless it is an emergency or dangerous situation ○ If I were you, I would begin looking into synching this data with Prolog/SharePoint/SAP and other existing management tools ○ If the tradesmen who are to be wearing these feel they are being 'spied on' they will not wear the tags ○ If you have a renovation job, the BIM must include areas not being worked on 	<ul style="list-style-type: none"> ○ Impact on insurance premiums must be considered ○ Location of workers does not indicate production ○ May not work on small projects ○ Need a tech savvy superintendent to use correctly ○ Office personnel must be knowledgeable about field operations to use this ○ Range limit and reception issues must be considered ○ Requires buy-in from subcontractors ○ RFID tag and reader management should be considered ○ Superintendent must personally verify productivity ○ Superintendents may feel disconnected with the jobsite ○ The invasiveness of this solution on personal freedoms must be considered ○ Unsure if this is practical ○ Workers sometimes have to move through different zones ○ Would not work to track productivity

Table 5.41: Codes derived from comments leaning towards a cautious approach about the framework to monitor the health and safety of construction workers using RFID and BIM

5.11 Summary of Framework Validation

Thirteen statements were presented to construction superintendents to validate the framework to monitor the movement of construction using RFID and BIM. The results indicate that five of the statements received an agreement of over 90% of the respondents, six of the statement received 80% or more agreement and two of the statements 50% or more agreement from construction professionals, as shown in Table 5.43. Only two statements were marked with a disagreement of more than 10% and the remaining eleven statements were disagreed between 0% to less than 5% of construction professionals

responding to the survey. This suggests overwhelming agreement to a majority of the framework and moderate to high agreement for two parts of the framework.

The open-ended questions cannot be used to count the number of positive or negative/cautious comments as not everyone chose to comment on the framework. However, considering the codes generated using thematic analysis, there were significantly higher positive comments than negative/cautious comments (65 ‘Positive’ versus 23 ‘Cautious Approach’). Almost every written response, even if they sided with taking a cautious approach, was encouraging and agreed that the framework could be used in certain scenarios, as depicted by the comment: *“I honestly don't see a super using it unless it is an emergency or dangerous situation”*.

Owing to the statistical summary presented in each scenario, the high levels of agreement about eleven of the thirteen statements, agreement among experienced construction personnel about the usefulness of the proposed framework, the textual analysis of the comments presented in section 5.10 and the summary presented in Table 5.42, the framework to monitor safety of construction workers using RFID and BIM is considered validated.

Statement	Agree	Neutral	Disagree
Scenario 1	96%	4%	0%
Scenario 1A	92%	6%	2%
Scenario 1B	50%	36%	14%
Scenario 2	97%	2%	0%
Scenario 2A	97%	1.5%	1.5%
Scenario 2B	94%	5%	1%
Scenario 3	80%	17%	3%
Scenario 3A	86%	12%	2%
Scenario 3B	85%	12%	3%
Scenario 4	81%	15%	4%
Scenario 4A	85%	12%	3%
Scenario 4B	59%	25%	16%
Overall Framework	81%	16%	3%

Table 5.42: Snapshot view of data showing levels of agreement, neutrality or disagreement regarding the framework

5.12 Summary

This chapter presented the procedures undertaken to validate the conceptual framework to monitor the movement of construction workers using RFID and BIM. The development and deployment of an Internet survey was presented and the analysis procedures to interpret the results from the survey were described. The quantitative and qualitative data from the survey was presented together with a summary analysis of the data to validate the conceptual framework. The next chapter presents the development of a proof-of-concept software prototype to demonstrate the implementation of aspects of the framework.

CHAPTER 6

DEMONSTRATOR PROTOTYPE DEVELOPMENT & EVALUATION

6.1 Introduction

In the previous chapter, the conceptual framework for site safety monitoring by tracking the location of construction workers using RFID and BIM was validated. The implementation of the proposed framework must be done through custom software since a commercially available solution for the purpose was not found. Software creation is an expensive and time consuming undertaking and is beyond the scope of this study. However, proof-of-concept software prototype may be used to demonstrate the effectiveness of the proposed framework to monitor the movement of construction workers within a site for safety purposes. In this chapter, the procedures undertaken to develop and evaluate a prototype for implementing the framework for monitoring workers using RFID and BIM is presented.

6.2 Software Prototyping

Software prototyping is the process of creating an inexpensive proof-of-concept version of the software for evaluation, requirement gathering and eventually developing a custom software (Smith, 1991). For the purpose of this research the software prototype must show the movement of construction workers in a 3D environment. As researchers Sacks et al.(2013) have described, implementing a technological innovation on an actual construction site requires unrealistic resources in many cases. The construction field personnel would need to be trained on the new technology, furthermore, a construction site where the participants are open to the implementation of the proposed application is difficult to find. In the case of implementing RFID technology, several privacy concerns have to be addressed including what data would be recorded, how long it would be stored, who would have access to it and what will the data be used for. Managing the RFID tags would require considerations on part of the general contractor in terms of who would store the tags, how would the tags be issued, who would pay for the tags and other related issues. These issues are deemed beyond the scope of this study and were not explored.

For the proposed framework of RFID and BIM based location tracking to be successfully implemented, every worker on the construction site must agree to wear an active RFID tag on their person. In most construction projects the general contractor outsources major parts of the work to subcontractors. It would be necessary that the general contractor

declare the proposed use of RFID and BIM based location tracking in the contractual phase of the project. The language in the contracts must require all personnel of each subcontractor to adhere to the safety regulations of the project and the regulations should include language requiring all personnel to carry an active RFID tag on the construction site. Conducting a study of that magnitude on a live construction project requires an ethnographic and longitudinal approach.

The research submitted for this thesis must adhere to strict university guidelines for on-time completion. For the framework to be implemented on a construction site for evaluation purposes, the researcher must be involved from the very early stages of a construction project, which is unrealistic considering that the researcher is not an employee of a construction firm. Therefore, in this research, volunteers will be used as actors in simulating construction activities rather than construction workers on an actual site. These volunteers will be referred to as workers in this chapter to minimise confusion for the reader.

The location of these workers within the test site will be gathered using RFID tags and RFID readers. A 3D virtual environment using the visualisation aspects of BIM will be created. A controlled site will be chosen to test the prototype. The movement of workers within the site will be represented in the 3D virtual environment by combining the tag data with the BIM model. A detailed description of the prototype creation process is described in Section 6.3 of this chapter.

6.2.1 Scenario Evaluation

A central concept of software prototype development is that not all aspects of the custom software will be developed for the purpose of evaluation in the initial phase (Budde et al., 1992). In the context of this prototype, the term ‘evaluation’ is used to test if the scenarios requiring superintendent intervention, described in the framework can be created in real time, in a virtual environment. A scenario would be considered successfully implemented in the prototype, if the end-user view displays information that can be used by the superintendent for making safety related decisions. These views must be consistent to those presented in Appendix 5.2 of the Internet survey. In the development of the

prototype for study, the following scenarios of the framework will be developed and evaluated, as shown in Figure 6.1:

- Demonstrate location of workers by colour coding them based on their trade
- Demonstrate effectiveness of managing emergency/critical situations
- Demonstrate automatically alerting workers entering a prohibited area
- Demonstrate identification of congested areas within the construction site
- Demonstrate remote monitoring by observing workers using a web browser

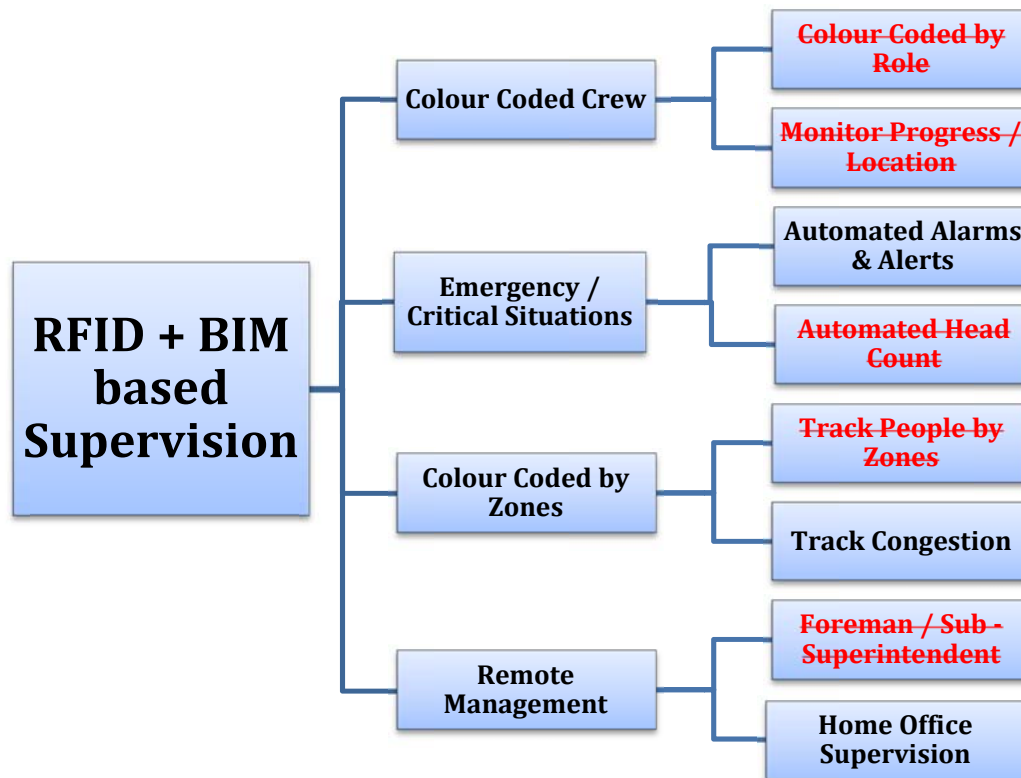


Figure 6.1: Scenarios to be tested by using the software prototype

The scenarios of the framework that will be evaluated by using the proposed prototype are presented in Figure 6.1. The scenarios of the framework that will not be tested include tracking workers based on their role, tracking progress of work based on worker location, automating the head count process for emergency evacuation, tracking workers by zones within the site and use of the proposed framework by foremen or trade superintendents.

Since the test will be conducted in a simulated environment with a limited number of workers and over a limited period of time, participants will not be separated by roles but will be categorised by their assumed trade. Progress of work will not be estimated based on location of workers, as the simulation would only last a limited amount of time for a limited number of workers. Similarly, the test will be conducted within a limited amount of physical space; therefore the site will not be split into zones to track the movement of workers. However, the framework will be tested to see if too many workers are present in one location, i.e. to test for congestion on site.

6.2.2 Software Prototyping System Requirements

The purpose of developing the software prototype is to demonstrate that the proposed framework for tracking the movement of workers using RFID and BIM can be implemented, using currently available technology. The software prototype must show a working model of the illustration shown in Figure 6.2 and similar variations of the same. These variations must include the various scenarios that are proposed to be tested by the software prototype.

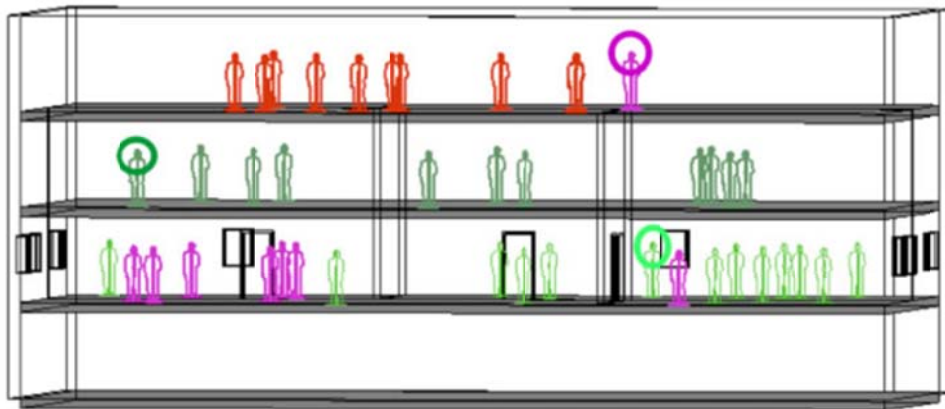


Figure 6.2: Illustration depicting workers on a construction site

The development process for the software prototype must include the following considerations:

- Construction workers will have to be tagged with an active RFID tag

- A BIM model will be needed for depicting the movement of workers within a construction site
- A suitable site will be needed to conduct evaluation of the framework with construction workers
- Active RFID tag data must be recorded and the location of workers must be determined within the test site
- The BIM model must show the approximate location of the workers within the model using each of the proposed scenarios to be tested.

6.3 System Architecture for Prototype Development

In this section, the choice of hardware and software tools used for the development of the proposed software prototype is described. ‘System Architecture’ can be considered as an abstraction showing the methodology adopted to develop a software solution (Northwestern University, 2004). The proposed system architecture for developing the prototype to implement the location monitoring based safety framework is presented in Figure 6.3. A layered approach is adopted for developing the prototype, including the ‘Hardware Layer’, ‘Storage Layer’, ‘Calculation Layer’, ‘View Layer’ and the ‘Display Layer’. The choices made and the procedures used at each layer of the system architecture are discussed in subsequent sections.

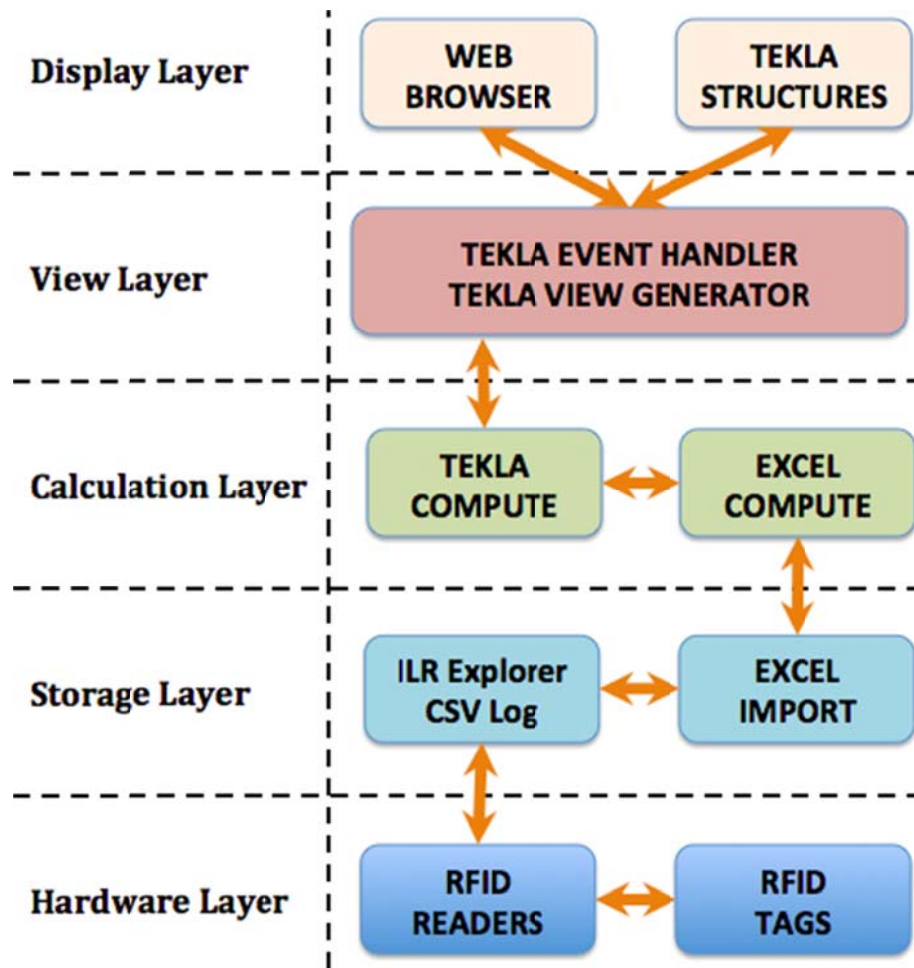


Figure 6.3: System Architecture for development of demonstrator prototype to implement RFID + BIM based safety monitoring framework

6.3.1 Hardware Layer

Several commercial solutions are currently available that provide hardware and software solutions in regards to RFID technology including ‘Atlas RFID’, ‘Identec Solutions’, ‘Motorola’, ‘Texas Instruments’, ‘RF Code’ and others. For the purpose of this research ‘Identec Solutions’ was used for RFID hardware. The choice was made based on the least expensive offer received from RFID manufacturers for the equipment and the technical support provided by the vendor to successfully operate the equipment. Five ‘iPort-MB’ readers with Ethernet host were obtained, as shown in Figure 6.4. The ‘iPort-MB’ readers work on 915MHz frequency and are capable of reading 100 tags per second. These

readers have the necessary hardware so that they may be attached to a wall or an object. Twenty RFID tags that are about the size and shape of an identity card form used by a typical organisation were obtained, as shown in Figure 6.4. The tags also have a hole in the plastic casing so that they may be attached to a person or an object. These tags and readers work on 915MHz frequency with tags sending a beacon capable of transmitting up to a 100 meter distance (Weinstein, 2005). The antennas attached to the readers are capable of reading tags from a distance of 100 meters as well. The tags also have a built in memory of 9 bytes.



Figure 6.4: iPort-M RFID reader and ID card form factor RFID tags

6.3.2 Storage Layer

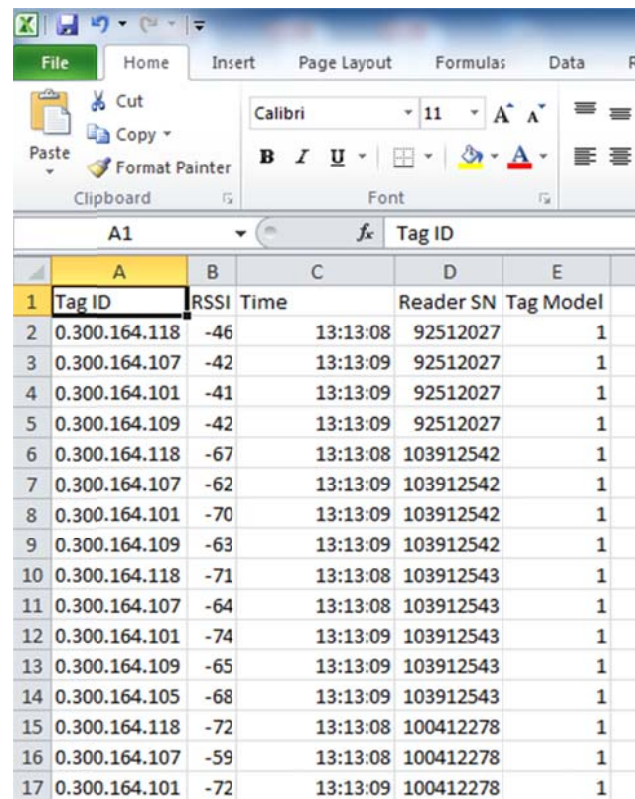
In an enterprise system, the tag data received by each reader would typically be stored in powerful database system such as ‘Oracle Systems’ or ‘Microsoft SQL Server’ which provide robust data storage and backup systems built in to them. However, significant technical and monetary resources are needed to develop a full-bodied database backend to the proposed software prototype application. For the purpose of the demonstrator software prototype, the expense of time and money to implement a robust data storage system for the tags was deemed beyond the scope of this research.

Identec RFID technologies provide a proprietary API that can be used for reading and recording data from the RFID tags. Storing the RFID tag ping data into a robust database such as SQL Server is typically how the data is recorded. Identec also provides a toolkit named ‘ILR Explorer’ to read and log all tag information as show in Figure 6.5.

Tag	Antenna 1	Antenna 2	Last Contact	Contact Count	Last Reader	Age Count	Model
0.300.164.107		-68	5:56:02 PM	308	5	26	iBL
0.300.164.118		-69	5:56:01 PM	302	4	26	iBL
0.300.164.102		-71	5:56:02 PM	314	5	27	iBL
0.300.164.106		-74	5:55:59 PM	299	4	26	iBL
0.300.164.104	-48		5:56:00 PM	300	5	26	iBL
0.300.164.115	-41		5:56:01 PM	296	1	26	iBL
0.300.164.109		-68	5:56:00 PM	305	5	26	iBL
0.300.164.108		-63	5:56:02 PM	306	5	26	iBL
0.300.164.101		-69	5:55:58 PM	293	3	26	iBL
0.300.164.105		-73	5:55:59 PM	292	4	26	iBL
0.300.164.103		-62	5:56:00 PM	294	2	26	iBL

Figure 6.5: ILR Explorer to read and record RFID tag data

The ILR Explorer allows the information shown in Figure 6.5 to be continuously logged in a text file in a ‘Comma Separated Values’ (CSV) format. In the conduct of this research, the ILR Explorer was used and the data from the CSV log file was used for further processing. The CSV data was programmatically brought into an Excel workbook at one-minute intervals. A sample of the CSV data opened using Microsoft Excel is shown in Figure 6.6. As part of this data the ILR Explorer stores information about each tag that was read including which reader read a particular tag, the time of the reading, the ‘Received Signal Strength Information’ (RSSI) for each reading. The VBA code used for importing the data into the spreadsheet is presented in Appendix 6.1 of this thesis.



	A	B	C	D	E
1	Tag ID	RSSI	Time	Reader SN	Tag Model
2	0.300.164.118	-46	13:13:08	92512027	1
3	0.300.164.107	-42	13:13:09	92512027	1
4	0.300.164.101	-41	13:13:09	92512027	1
5	0.300.164.109	-42	13:13:09	92512027	1
6	0.300.164.118	-67	13:13:08	103912542	1
7	0.300.164.107	-62	13:13:09	103912542	1
8	0.300.164.101	-70	13:13:09	103912542	1
9	0.300.164.109	-63	13:13:09	103912542	1
10	0.300.164.118	-71	13:13:08	103912543	1
11	0.300.164.107	-64	13:13:08	103912543	1
12	0.300.164.101	-74	13:13:09	103912543	1
13	0.300.164.109	-65	13:13:09	103912543	1
14	0.300.164.105	-68	13:13:09	103912543	1
15	0.300.164.118	-72	13:13:08	100412278	1
16	0.300.164.107	-59	13:13:08	100412278	1
17	0.300.164.101	-72	13:13:09	100412278	1

Figure 6.6: ILR Explorer to read and record RFID tag data

6.3.3 Calculation Layer

Microsoft Excel spreadsheets were used to interpret RFID tag data from the CSV log file, owing also in part due to the researcher's comfort level with the spreadsheet software. The data from the CSV log file was imported into the Excel spreadsheet using visual basic code and Excel macros. The data from the CSV file was programmed to be imported every one minute into the spreadsheet. It must be noted that the precise location of an RFID tag cannot be determined. Determining the approximate location of RFID tags in space is a challenging problem since RFID radio waves are reflected by magnetic fields and metal objects (Goodrum et al., 2006). This issue continues to be an active area of research and the technology is being continuously tested and improved (Montaser and Moselhi, 2014; Chen and Wang, 2014). Employing an extensive network of readers and using triangulation algorithms, it is possible to attain a high level of certainty for identifying a tag's location. Triangulation techniques are some of the most popular

methods currently available to interpret the location of RFID tags based on the ping data (Kashkouli Nejad et al., 2013). In the pursuit of this research, the best RSSI signal strength and the timestamp of the tag read were used to determine the approximate location of the RFID tag. The location of the RFID tag obtained using this method can be inaccurate due to reflection from metals on active RFID radio waves; however for the purpose of this research, the location data is considered adequate as the purpose of the software prototype is to demonstrate that the framework developed can be used in the construction industry. The calculations to interpret the location of the tag were done within the spreadsheet. First, the location of the RFID readers was determined by manually measuring the distances in the test site. The readers themselves were placed in strategic locations so that they would potentially cover the entire area where the workers would be present, as shown in Figure 6.10. The spreadsheet was setup so that it would check for the latest ping recorded by each reader for a certain tag and use the one with the lowest RSSI as the nearest reader. The X, Y and Z coordinates for each RFID tag within the space of the test site were then determined in the spreadsheet, by offsetting the coordinates based on the coordinates of the reader and RSSI obtained from the ping data.

6.3.4 View Layer

Several BIM authoring software programs such as Autodesk Revit, Tekla Structures, Bentley Building Systems and Graphisoft ArchiCAD are commercially available in the marketplace. Other BIM related software such as Navisworks, Synchro and Solibri are also available for model checking, 4D CAD and other purposes. It is possible to use these products as well, for the purpose of creating a software prototype proposed in this research. Several of these programs also provide an open API that can be used by end users and software developers to create custom solutions. For the purpose of this research Tekla Structures was used due to the researcher's familiarity with the software. Tekla also offered free hands-on API training to students that the researcher was able to attend.

A BIM model for the test site was developed using 'Tekla Structures'. The software prototype was designed as an 'add-on' to the BIM model developed in Tekla Structures. Tekla API was used to import the data from the spreadsheet in the calculation layer, in to the Tekla BIM model. The data was then used to draw workers within the Tekla BIM

model. Microsoft Visual Studio was used to develop the software prototype. The programming language ‘C#’ was used to develop the software prototype. The code used in importing the spreadsheet data and showing the location of workers within the Tekla model, for the various scenarios tested is presented in Appendix 6.2 of this thesis. The form showing the buttons to test the various scenarios is presented in Figure 6.7. Tekla API ‘event handlers’ were created to test each of the scenarios depicted in the form shown in Figure 6.7.

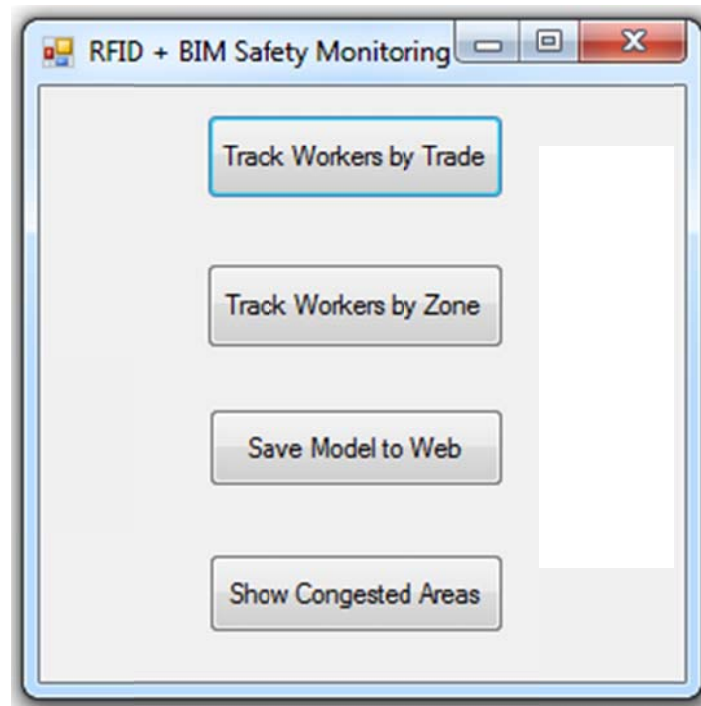


Figure 6.7: Form with buttons to test various scenarios in the framework to monitor construction workers by using RFID and BIM

6.3.5 Display Layer

The display layer used in the development of the prototype is essentially the end-user view of the proposed framework. Since the evaluation of the limited functionality prototype was conducted in a simulated environment, the primary researcher was considered the end-user, as in the superintendent or safety officer. The proposed framework was displayed in the BIM authoring tool, Tekla Structures 20.0 platform. End-user views were also exported to a web page for viewing on a mobile device or laptop.

Detailed descriptions of the scenarios evaluated as part of the display layer of the architecture are presented in Section 6.4 of this chapter.

6.4 Scenario Evaluation using the Software Prototype

Since a decision to not use an actual construction site was made, the framework implementation had to be done in a controlled indoor environment. The proposed framework could work in an outdoor environment as well; however, since this prototype is used for demonstration purposes only, the chosen indoor environment was considered adequate. Furthermore, the availability of autonomous power is required in an outdoor environment, which was unavailable to the researcher. The model depicting the entire facility where the evaluation occurred is shown in Figure 6.8.

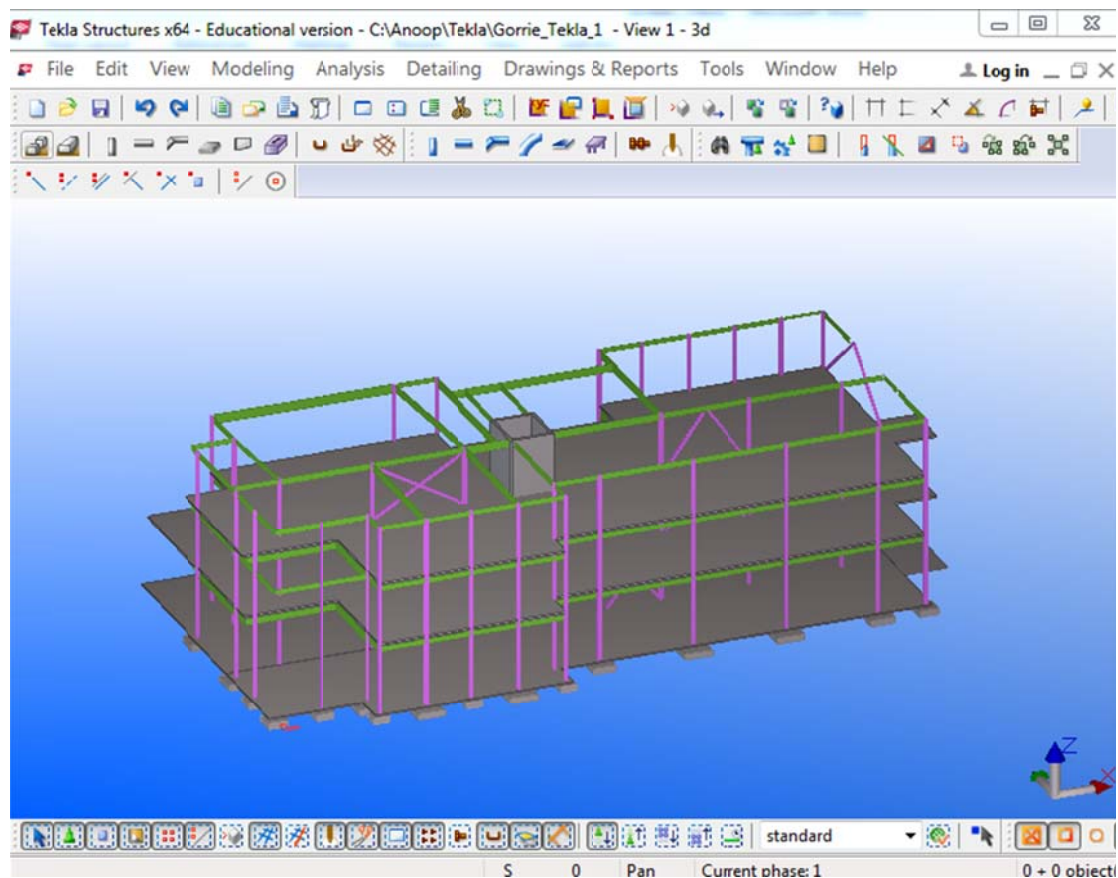


Figure 6.8: Tekla model for the building where RFID and BIM framework was tested

The test site is an existing laboratory in the McWhorter School of Building Science at Auburn University. Several hundred students use the building during each working day and over twenty-five faculty and staff members have their offices within the building. In an effort to minimise disruptions to the occupants of the building, only one room (the laboratory) within the building was used to test the framework using RFID and BIM. Some physical views of the room where the evaluation occurred are shown in Figure 6.8. The room measures approximately 3000 square feet in area.



Figure 6.9: Physical views of the room where RFID and BIM framework for monitoring construction workers was tested.

The Tekla model shown in Figure 6.6 was modified to show only the room where the evaluation was conducted. The modified Tekla model is shown in Figure 6.10. The figure also shows the location where each of the five RFID readers was placed for conducting the tests.

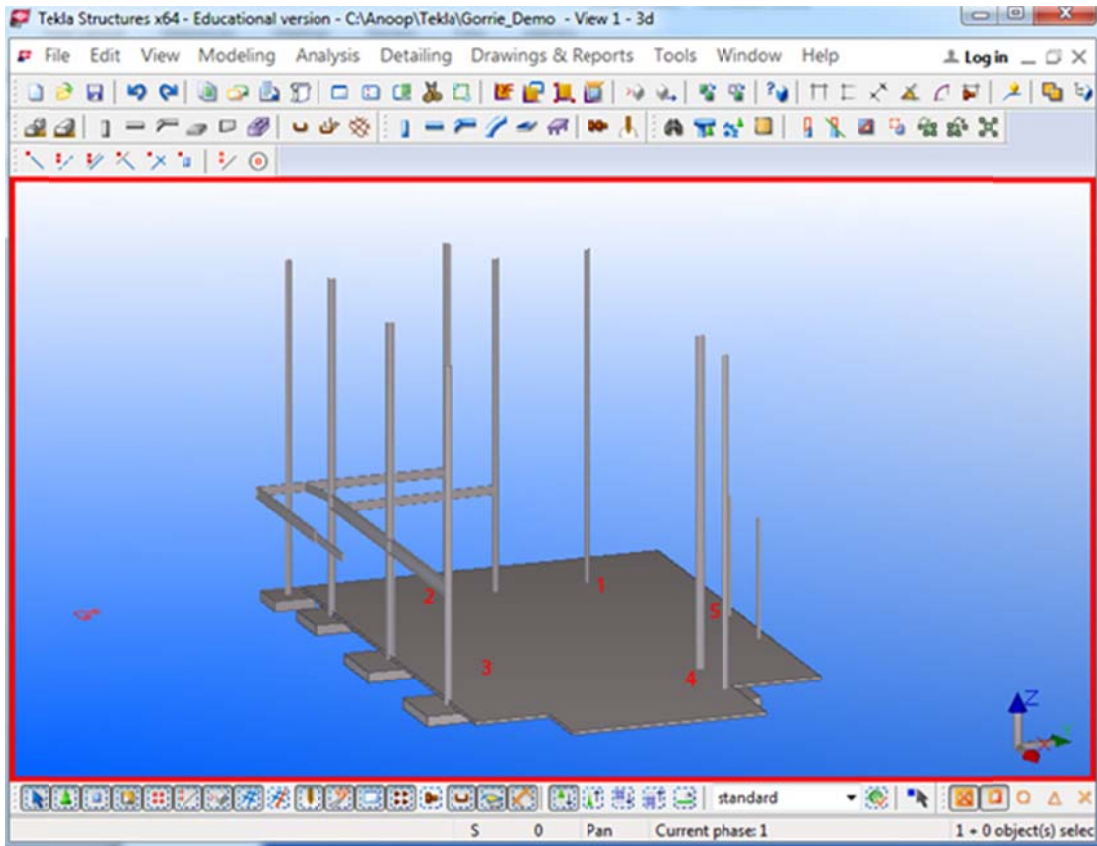


Figure 6.10: Modified version of the Tekla model to show only the room where the framework was tested

Seven construction workers participated in evaluating the various scenarios presented in the framework to monitor the movement of construction workers using RFID and BIM. Each of the seven construction workers wore the active RFID tag, as highlighted in Figure 6.11.



Figure 6.11: Construction workers wearing an active RFID tag

6.4.1 Location of Workers by Trade

Each of the construction workers participating in the study was associated with a particular trade, as shown in Table 6.1

Worker Name	Tag-ID	Trade
Hampton Vann	0.300.164.115	A
William Cochran	0.300.164.118	B
Hunter Himes	0.300.164.105	A
Jake Utley	0.300.164.101	B
Brandon Landtroop	0.300.164.102	A
Andrew Carroll	0.300.164.103	C
Taylor Schmidt	0.300.164.104	C

Table 6.1: Construction workers, RFID tag IDs and respective trades

In the initial few minutes of wearing the tag, the workers were told to walk around the site and their location was calculated at various instances. A screen capture of the framework, while it was working, is presented in Figure 6.12. The location of workers was being updated every one-minute; therefore the location of workers on the Tekla model was not

consistent with the actual location of workers within the site. However, the location presented was also never more than one minute out-dated. The delay was caused by the decision to not develop a robust database backend to the application. The algorithm used in the VBA code checks the entire tag data to estimate the best location of the tag, each time it is run. The 5 readers employed were adding several hundreds of tag reads per minute to the log file. By using Excel as the engine to calculate the location, it was found that the spreadsheet was progressively getting slower to calculate the location of the tag, hence the one-minute delay was introduced. The purpose of the software prototype is to demonstrate that the framework could be implemented using technical tools and not to create a robust system for evaluation purposes. Figure 6.12 demonstrates that construction workers can be represented in a BIM model by colour coding them based on their respective trade, by combing RFID and BIM.

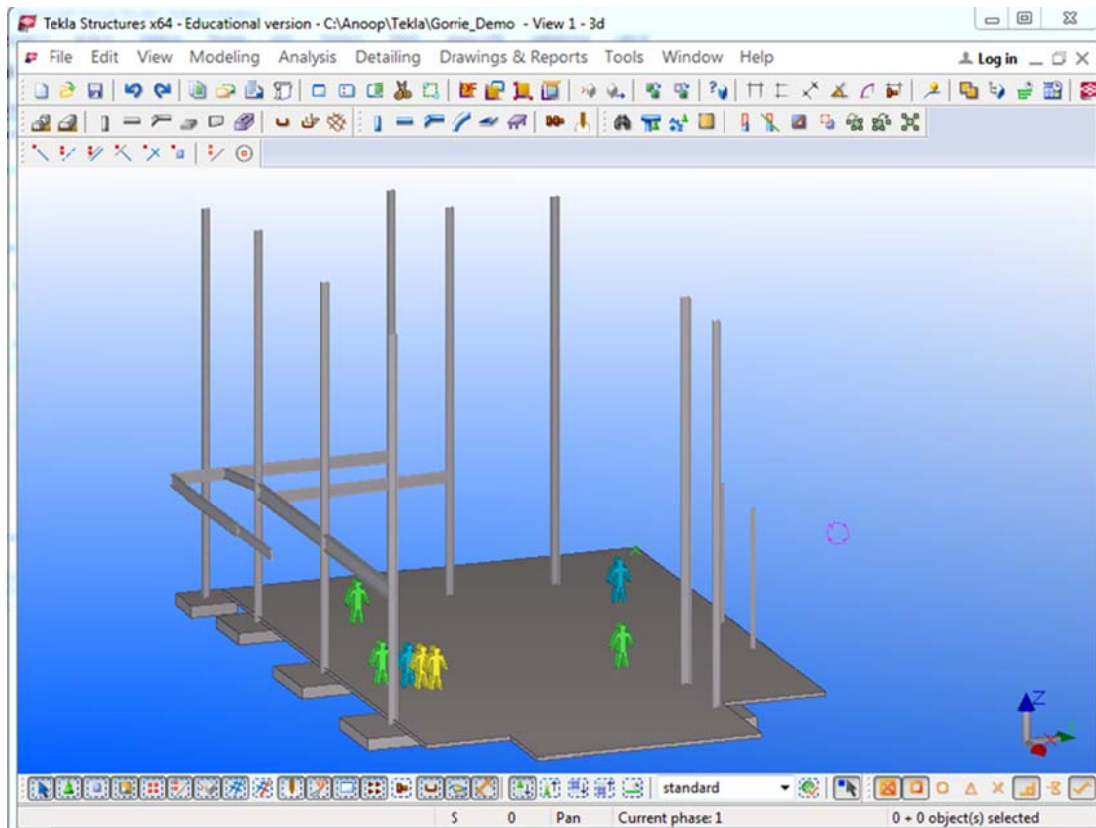


Figure 6.12: Screen capture of tracking workers by trade scenario

6.4.2 Manage Emergency / Critical Situations

Each construction worker was informed that the area around RFID reader 5 was to be considered a forbidden zone. Workers that were not close to reader 5 were depicted in green colour and if workers came too close to the area were depicted in red colour within the model, as shown in Figure 6.13. In evaluation of this scenario it was found that the location of workers depicted was about one minute delayed, as in the previous case. Figure 6.13 demonstrates that the proposed framework can be used to track workers by colour coding them when they enter critical areas within a construction site, using the proposed framework.

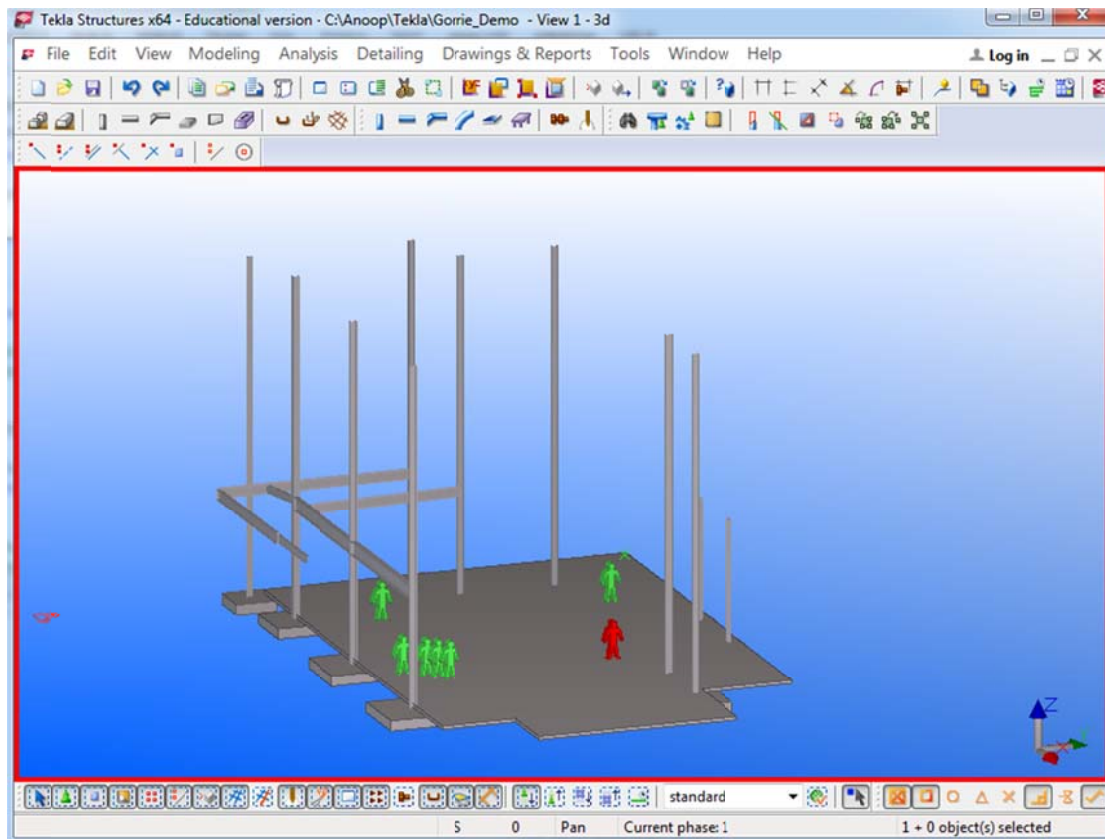


Figure 6.13: Screen capture of tracking workers for critical situations scenario

6.4.3 Automated Alarms for Workers Entering Forbidden Zones

In their study proposing a safety management system using visualisation tools, Park and Kim (2013, p. 100) state “If an active RFID is applied to identify worker location, an

immediate warning signal can be delivered to workers and a proactive accident control would be possible in the site as well.” The demonstrator software in this study was used to perform exactly this action. In addition to tracking workers when they enter a critical zone, construction workers were sent a text message to their mobile phones when they got too close to the forbidden zone. The message that workers received is presented in Figure 6.14. This scenario was handled by the visual basic code in the Microsoft Excel VBA part of the software prototype development. Figure 6.14 demonstrates that an automated alarm can be sent to construction workers if they enter an unauthorised zone using the RFID and BIM framework of safety monitoring.

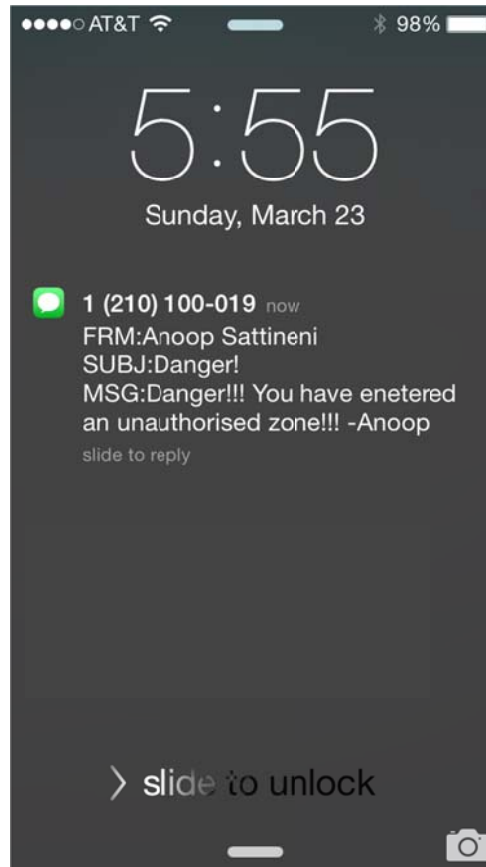


Figure 6.14: Text message sent to construction workers if they got too close to a forbidden zone within the test site

6.4.4 Tracking Congested Areas within a Construction Site

The site was considered as congested if all the workers congregated in one area of the site. The calculation to check if the location of all the workers was closest to one particular reader was performed in the spreadsheet VBA code. Construction workers were asked to stay close to one reader within the site for demonstration purposes, as shown in Figure 6.15.



Figure 6.15: Construction workers congregated within one area of the site

The Tekla model was evaluated to see if congested areas could be highlighted within the construction site. The scenario depicted in Figure 6.15 was recreated in the Tekla BIM model, as shown in Figure 6.16, using information gathered by the RFID readers. Congested area was depicted by colour coding all the workers within the congested area in red. Figure 6.16 demonstrates that the proposed framework can be used to highlight congested areas within the construction site.

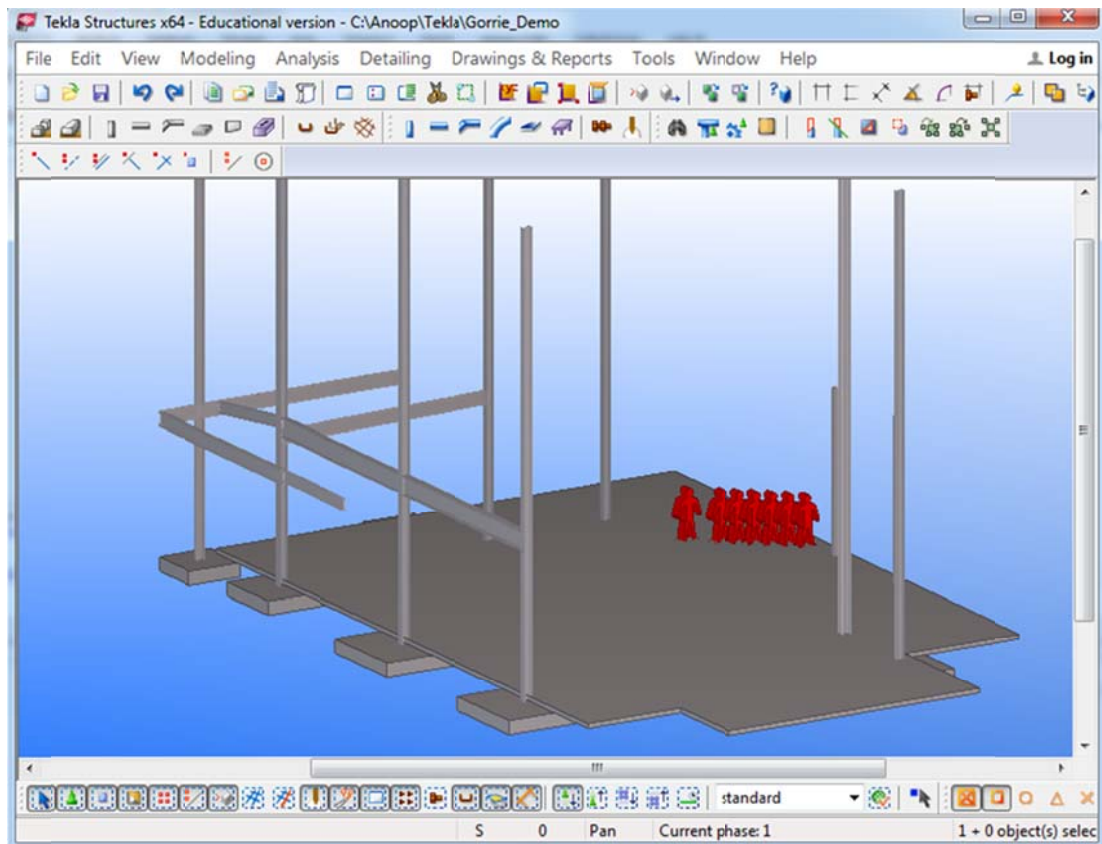


Figure 6.16: Tekla BIM model showing congested area within the construction site

6.4.5 Remote Monitoring Worker Movement using a Web-Interface

Tekla API was used to save the BIM model as a webpage. The webpage showing the Tekla model is presented in Figure 6.17. The model can be opened using the Internet Explorer web browser. The webpage was opened on the test site and not in a remote location. However, since the model can be saved as a webpage, the model will be viewable from any location with access to the Internet. Figure 6.17 demonstrates that the proposed framework can be used to remotely monitor the movement of construction workers on the site from any location with Internet access.

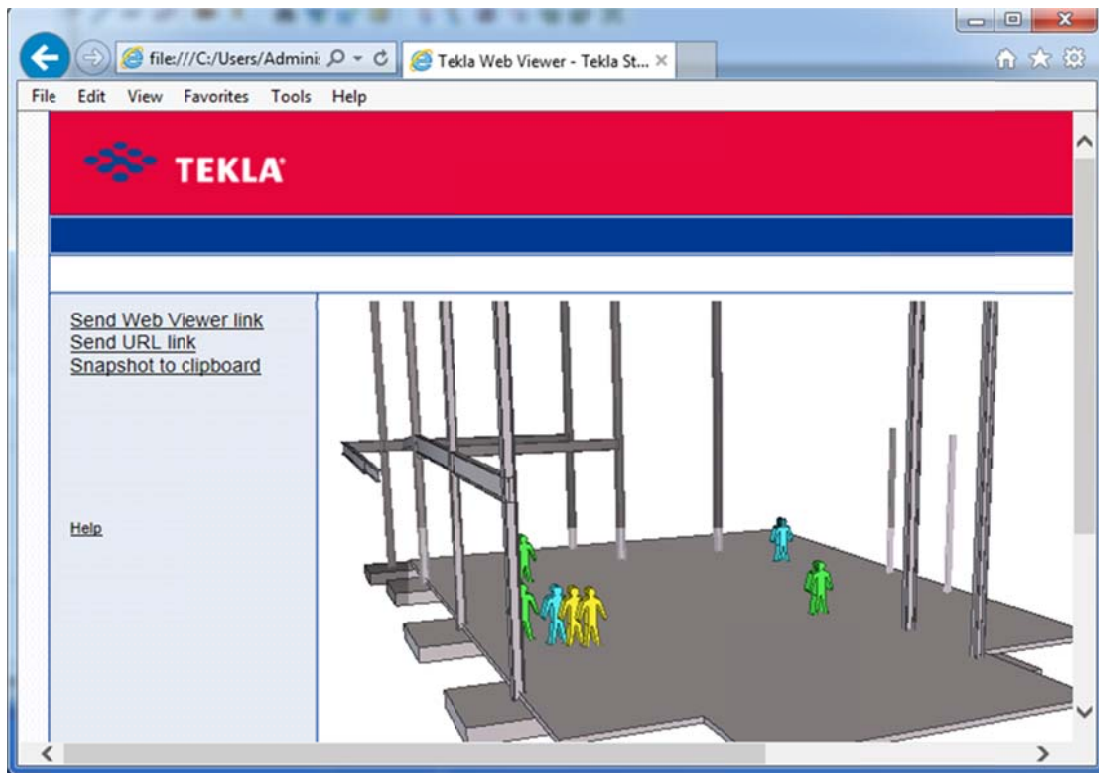


Figure 6.17: Tekla BIM model showing the location of workers by trade as seen using the Internet Explorer web browser

6.5 Considerations for Working Prototype Development

The prototype developed as part of this research has limited functionality. The prototype was tested in a simulated construction environment with volunteer actors. The results of the simulation demonstrated that RFID and BIM combination could be used to track location of construction workers for safety purposes. However, the simulation conducted, by its very design, is a narrow depiction of actual scenes on a construction site. This section of the thesis considers the implementation of the proposed framework in an actual construction environment. Issues concerning preparing participants for using the proposed framework, logistical issues to implement the framework and technological issues to create a prototype to implement the framework are discussed. It must be noted that this is only a brief discussion of field implementation issues as a detailed investigation is beyond the scope of this research.

6.5.1 Participant Preparation

Feedback from construction industry professionals suggests that the proposed framework to monitor location of construction workers for safety purposes can be useful on site. However, workers and superintendents would need to be trained about the framework before it can be successfully implemented. First, workers and superintendents must be made aware of the safety risks associated with the lack of monitoring the movement of people on the construction site. The safety scenarios of the proposed framework must be described as another means to ensure safety, rather than as a tool to spy on workforce. Comments from industry participants about this issue indicate that for the proposed framework to be successful, workers must accept the relevance and validity of the framework and must not view this as big-brother technology. Similarly, superintendents must be cautioned that the framework only shows the location of workers and may be used for safety purposes, but that it does not show what workers are actually doing at those locations. Superintendents must be cautioned that the framework is not a substitute to field monitoring procedures as it relates to safety, but rather must be used as an additional tool for knowing the location of workers for safety purposes. Contractual language within subcontracts must be amended to reflect the implementation of the proposed framework for safety purposes. Language must explicitly state that all subcontractor personnel entering the site would be required to participate in the RFID enabled framework of location monitoring. It may be necessary to assure subcontractors that the proposed framework would be used for safety purposes only. Lastly, it would be prudent to have disciplinary measures in place to deal with workers that do not adhere to the rules of implementing the framework or try to game the system in any manner.

6.5.2 Logistical Issues

The reliability of the RFID and BIM based prototype of location monitoring depends on all workers wearing an active RFID tag on the construction site. It may be necessary to appoint a single point-of-contact (i.e. single administrator) on the construction site to handle all issues related to the framework's implementation. The designated employee would be required to have some technical knowledge regarding related issues such as RFID technology and BIM technology. It would be the responsibility of the administrator to ensure that each tag is functioning properly, has a working battery and that each reader

is picking up the tag data from the workers. Every person entering the site must be given a particular colour code, given their trade or association with the construction site, to reflect the same in the working prototype. Workers, superintendent staff and visitors or specifically the RFID tag given to them must be associated with an appropriate safety clearance to show within the prototype when they enter an unauthorised zone. Each worker must also be declared to be working in particular zone(s) on the construction site so that superintendent or safety staff can monitor the same using the prototype. Superintendents and foremen for all trades must be explicitly identified to ensure that their location can also be shown in the working prototype. The mobile phone/device contact information for each worker and superintendent must be kept on file and up to date so that emergency messages can be transmitted when necessary. A known location must be established as the muster point during an emergency situation and an RFID reader must be placed at that location. The prototype administrator would need to work closely with the superintendent and safety personnel to regularly update information about safety zones and working zones in the proposed framework. The administrator would also need to add or move RFID readers within the construction site, as the job progresses. The superintendent and safety staff must have access to the prototype as they move about within the site; therefore mobile devices enabled with network connectivity must be made available for them.

6.5.3 Technological Issues

The development of a prototype to implement the framework for worker location based safety monitoring must take in to account several considerations. The storage of tag data must be done in a robust and secure environment such as an advanced database management system. Backup systems must be used to ensure that data loss due to any reason is kept to a minimum. The data must be secured so that unauthorised personnel cannot use it or that it cannot be used for unauthorised purposes. A separate module must be created for the administrator of the prototype so that information about each tag and reader may be added to the database. The display model used for the prototype must consider a generic solution rather than build a solution around a single BIM model, so that the prototype is reusable. Views created using the prototype must be robust and show the data in as close to real-time as possible.

6.6 Summary

This chapter has presented an overview of the development of a demonstrator software prototype to implement the framework to monitor the movement of construction workers using RFID and BIM for safety purposes. The hardware and software components utilised to develop the software prototype were discussed. The software prototype was used to demonstrate the practicality of implementing certain aspects of the framework to monitor the movement of construction workers using RFID and BIM. A brief discussion about developing the working prototype is also presented. The tests conducted in a controlled environment revealed that the framework can be used as described in Chapters 4 and 5. In the next chapter the conclusions that can be drawn from the conduct of this research are presented.

CHAPTER 7

CONCLUSIONS AND RESEARCH SUMMARY

7.1 Introduction

The previous three chapters presented the findings surrounding the main theme of this research, i.e. to use location monitoring of workers using RFID and BIM, for safety purposes. In this chapter a summary of the findings and their implications are discussed. The novelty of this research and the contributions of this research concerning construction site safety monitoring issues are discussed. There is consensus within the scientific community that there are limitations with conducting any research (Saunders et al., 2009). The limitations associated with this research are presented in this chapter. Finally, future research that may be continued based on the findings of this research is discussed.

7.2 Conclusions from Literature Review

“The significance of your research and what you find out will inevitably be judged in relation to other people’s research and their findings” (Saunders et al., 2009, p. 60). This quote eloquently describes the two aspects of conducting literature review, namely to understand the state of current knowledge in any field and to juxtapose ideas from other researchers’ to refine one’s own research process. The researcher had personal experience with several aspects related with the research conducted in this study including RFID technology, BIM and construction supervision. In order to ensure that the conclusions drawn from these personal experiences were relevant and mainstream views, a review of literature around surrounding issues was undertaken, along with a critical review of similar research. The other purposes of conducting the literature review were to gain a comprehensive understanding of the state of knowledge in these areas and to refine the research process for this study in light of findings from the greater scientific community. A review of the literature for ‘*Construction Safety*’, ‘*RFID*’ and ‘*BIM*’ was undertaken as part of this study. This review of literature allowed the researcher to achieve the objectives of *“Understand existing methods for construction site safety monitoring and supervision”* and *“Investigate possible uses of combining RFID and BIM technologies in the construction industry for safety purposes”*, outlined in Chapter 1 of this thesis. This analysis of the literature was continued throughout the conduct of this research that spanned over four years.

- **Construction Safety and Site Supervision:** Construction is one of the most dangerous professions in the United States and worldwide. More than a thousand work place fatalities each year are attributed to the construction industry and the industry is consistently ranked as one of the worst, in terms of fatalities per capita workers. Majority of these accidents occur due to unsafe acts by employees, whereas a smaller minority are attributed to unsafe conditions on the construction site. The attitudes and organisational values within a company contribute in large part to the safety climate on its construction sites. Construction companies undertake several strategies to mitigate the safety risks associated with construction activities including training workers, use of technology applications and effective supervision of workers. Designers have a role to play in the safety outcomes for a construction project; however, there is a gap in the United States in terms of designers mandated to pay attention to safety aspects during the construction of their designs. Supervision is one of the key issues identified in ensuring that workers are following the safety directives and that a ‘culture of safety’ is prevalent on the construction site. The role of the construction superintendent however extends beyond safety, as the superintendent is also responsible for production and quality control, among other issues. The movement of workers within the construction site is one of the most common situations when accidents can occur.
- **RFID Technology:** The history of RFID technology is older than that of the modern personal computer. RFID technology has the potential to replace similar tracking technologies such as barcodes (Kumar, 2007). By electronically keeping track of objects and/or people, RFID technology has the potential to reduce labour and costs associated with tracking and inventory management. The use of RFID technology has been demonstrated in several sectors including the construction industry. Within the construction industry studies have shown that RFID technology can be used to optimise activities associated with material management, tool management, supply-chain management and facility management. The use of RFID technology to track workers for safety purposes has also been proposed (Carbonari et al., 2011).

- **BIM in the AEC Sector:** The use of BIM within the construction industry has been on the rise over the past decade (McGraw Hill Construction, 2012). There has been an explosion of commercially available tools for BIM within the past decade. The use of BIM for design, visualisation, cost planning, coordination, schedule management and other construction issues has been demonstrated by current research. Evidence suggests that BIM has quickly become the industry standard to enable communication between the various participants of the AEC sector for the design, construction and maintenance of a facility. There is also evidence to suggest that BIM will influence most or all aspects related to designing, building and maintaining facilities in the future.

- **Use of RFID and Visualisations for Safety Purposes:** Several studies have endorsed the use of RFID technology for real-time data gathering in the construction industry. Some researchers have used RFID with BIM and other visualisation tools for making safety related decisions (Arslan et al., 2014; Cheng and Teizer, 2013; Park and Kim, 2013; Zhang et al., 2013a). Studies have used this combination to visually represent the location of construction resources within a site, in a virtual environment, for safety monitoring purposes. However, it was found that these studies took a very technology centred approach to develop demonstrator software and have not fully addressed it from a more holistic perspective of activities and actors on the construction site. Issues such as understanding safety and movement of workers within the backdrop of activities occurring on site, the role of the superintendent in monitoring these workers and the contextual situations where the proposed technological solution could be used were not addressed.

7.3 Conclusions about Research Methodology

Saunders et al.(2009), describe research as a systematic way to find out things and propose the research onion as a comprehensive approach to conduct research. The research onion was used in the conduct of this study. The aim of this research was '*to develop a decision support framework for construction site safety monitoring by combining RFID with BIM in a virtual environment*'. A qualitative paradigm was adopted for conducting this study. The decision was justified as construction superintendents are

primarily responsible for maintaining safety on a construction site and superintendents' views are shaped by their experiences and values. Consistent with the qualitative paradigm, the stance chosen was a 'phenomenological' philosophy, 'subjectivist' ontology and 'interpretivist' epistemology in the conduct of this research. Site safety issues have to be studied within the context of the construction workers, superintendents, and site conditions, etc. Therefore an inductive research approach was chosen, consistent with the philosophical stance.

Multiple research strategies were employed, depending on the particular stage of this mixed-method study. The mixed-method research choice allowed qualitative plus quantitative data to develop and validate the proposed framework to monitor the movement of construction workers from a safety perspective. Semi-structured interviews were conducted to understand a comprehensive role of the construction superintendent, their views and experiences on safety, on monitoring the location of construction workers and their thoughts about the proposed method of monitoring construction workers. Thematic and content analysis of the interview data lead to the creation of a conceptual framework with scenarios under which the proposed method could be used for tracking the movement of construction workers. The conceptual framework was validated using an Internet survey instrument seeking input from construction industry professionals, about the proposed framework. The quantitative results of the survey validated the framework and therefore the conclusions drawn from the qualitative interview data. A prototyping methodology was used to create and evaluate the demonstrator software to implement the framework in a simulated construction environment.

7.4 Conclusions of the Findings

Data was collected and analysed at three different stages of the research. The data collection methods were briefly described in the previous section. In this section, findings from the various stages of conducting the research are described.

7.4.1 Conceptual Framework Development

Nineteen construction site superintendents in the Southern United States were interviewed in this phase of the study. The superintendents were asked about issues relating to their

role in a construction project, about their views and experiences about safety, about the importance of knowing and monitoring the location of workers on a construction site and their views regarding the proposed method of monitoring construction workers. The data revealed that the superintendent on a construction project is the ‘Go-To’ person regarding all operational and construction activities on site. They consider safety as a very important aspect of their daily responsibilities, as well as a moral obligation towards the workers on site. Safety is an issue that is at the back of their minds in everything they do and observe on the construction site. Planning for safety was a universal strategy adopted by the superintendents interviewed. Superintendents described accidents that took place in their personal work experiences and mentioned they were preventable if they were present to observe the activities taking place on site. Superintendents mentioned that knowing the location of workers was very important from a safety, as well as a productivity standpoint. On several occasions superintendents also mentioned that it would be nice to know the location of workers but described the impossibility of being at all locations at one time on a construction site. Virtually every superintendent interviewed agreed that the proposed framework could be effectively used to monitor the movement of construction workers on a site. They pointed to several situations where they would be able to use that information. The interview analyses led to the creation of a conceptual framework for monitoring location of workers using RFID and BIM, for safety purposes; therefore the objective of “*Develop a conceptual framework for site safety supervision based on location monitoring of personnel using RFID and BIM in a virtual environment*” outlined in the Introduction Chapter was achieved. The framework included four scenarios to track the movement of construction workers, as described below:

- To colour code workers based on their trade and role so that superintendents knew worker locations at all times, as well use it to gauge the progress of work.
- To use in emergency / hazardous situations to know where workers are present, to automate the head count process during an emergency evacuation and to alert workers when they enter a hazardous or forbidden zone.

- To use by splitting the construction site into various zones and representing workers in their respective zones and highlighting workers when they entered an unauthorised zone and also to identify congested areas within the site.
- For remotely monitoring the construction site when the superintendent is unable to be on the site, and to be used by construction foremen and subcontractor superintendents to track the workers under their purview. Personnel in the home office would also be enabled to gauge the progress of work, by considering the movement of workers.

The development of the framework in this thesis varies from other studies that have pursued the combination of RFID and visualisation technologies for safety purposes. Park & Kim (2013), Cheng & Teizer (2013), Zhang et al. (2013a) and Arslan et al. (2014) have all taken a technological approach to the issue and developed demonstrative software as a solution to site safety, based on visualising location monitoring of construction resources. The research in this thesis approached safety and supervision as a human activity, consulted practitioners to develop a framework for making safety related decisions based on location monitoring of workers using RFID and BIM, before developing a demonstrator software. Since superintendents have the explicit responsibility of monitoring safety on construction sites, their opinions were considered crucial about issues relevant to worker location monitoring for safety purposes. The framework considered contextual situations that are typical to a construction site in developing the framework for location monitoring of workers on a site.

7.4.2 Conceptual Framework Validation

An Internet survey was created to validate the framework to monitor the movement of construction workers using RFID and BIM, for safety purposes. The survey elicited 130 responses from the construction professional community. These responses were analysed using descriptive statistics. The survey presented each of the four scenarios and the proposed method for tracking construction worker location within the site, for making safety related decisions. A total of thirteen statements were presented to the survey respondents asking them to choose an option based on a Likert scale ranging from ‘Strongly Agree’ to ‘Strongly Disagree’. More than 80% of the respondents agreed with

eleven of the thirteen statements. More than 50% of the respondents agreed with the remaining two statements with three times as many respondents agreeing with the two statements as compared to the number of respondents that disagreed with the same. Responses were also analysed for construction professionals who had more than 15 years of experience in the industry. The results from the experienced respondents also indicated that they were in agreement with the larger construction community about the usefulness of the proposed framework. Respondents were also given an opportunity to provide written feedback via open-ended questions in the survey. These results indicated that a majority of the comments were positive and in favour of using the proposed framework. However, there was also some pessimism expressed by some of the respondents. Several comments were expressed about how knowing the location of workers does not necessarily indicate the progress of work. There was also a sentiment among some respondents that too much reliance on technology could lead to complacency on part of the superintendents. It must also be acknowledged that the framework may need further refinement when it is finally implemented in an actual construction environment. This issue is further discussed in the ‘Research Limitations’ section of this chapter. The framework was considered validated owing to the statistical data from the survey along with the positive comments received for the open-ended questions. Validation of the framework fulfilled one of research objectives outlined as “*Validate the proposed conceptual framework for site safety supervision using RFID and BIM*”.

7.4.3 Demonstrator Prototype Development and Evaluation

A software prototype was developed to demonstrate the effectiveness of monitoring construction workers using RFID and BIM for safety purposes. The software prototype was developed using commercially available ‘Identec Solutions’ RFID tags and readers. ‘Tekla Structures’ was used as the BIM platform to develop the solution. The prototype was used to track volunteer actors in a controlled indoor environment. These actors were tracked by depicting them in real-time within the BIM model. They were colour coded within the BIM model by their assumed trade, to show if they were in a hazardous area, to alert them when they entered a hazardous area, to track congested areas within the site and to remotely monitor their movement in a web browser. Text message alerts were sent to workers’ mobile phones that entered a pre-designated dangerous zone within the

simulated construction site. However, there was a one-minute delay in showing the data in real time due to the technological strategy adopted in developing the software prototype. However, this delay would be minimised in the creation of working software. Nevertheless, the objective of developing a demonstrator software prototype to implement the framework was achieved. The prototype was able to demonstrate that construction workers can be tracked for safety purposes, by using RFID and BIM, as proposed in the framework. Hence the final objective of the research to “*Develop and evaluate demonstrator software prototype to monitor site safety using the RFID and BIM framework*” was accomplished.

7.5 Contribution to Knowledge

The main contributions of this research as they relate to academic research and as they relate to safety practices in the construction industry, are presented in this section.

7.5.1 Academic Contribution

Studies have shown that RFID tags can be used in the context of safety on a construction site. Literature review has revealed that tracking construction workers using RFID tags for safety monitoring purposes has also been proposed (Lu et al., 2011). However, feedback from construction superintendents and construction industry professionals was not sought in developing that argument. This research was able to show there is widespread agreement within the construction community that a framework for safety monitoring using RFID and BIM can be useful. Literature has shown that RFID tags were used for numerous purposes on a construction site, including site safety. Literature has also shown that BIM is also being used in a number ways in the construction industry, including site safety. However, a theoretical argument for using of RFID and BIM for location monitoring of construction workers to make safety related decisions was not found in the literature. The feedback used from construction professionals in proposing the framework for this study corroborates and provides a theoretical basis for the work done by Park & Kim (2013), Cheng & Teizer (2013), Zhang et al. (2013a) and Arslan et al. (2014). The framework developed in this study can be used to conduct future research in determining the use RFID and BIM for safety purposes, as described in Section 7.7 of

this thesis. The results also presented several situations beyond safety that industry professionals said the framework could be employed.

7.5.2 Industry Contribution

This research was able to show that construction superintendents have several reasons to know the location of workers within the site, beyond maintaining health and safety; however this research has shown that there is no known method that is currently widespread in the construction industry to facilitate the site superintendent to monitor the location of workers. This research presents a framework for safety monitoring of construction workers using their location on a construction site. The framework was developed and validated by input from construction professionals and presents specific scenarios in which the proposed framework can be used. The demonstrator software was a rudimentary glimpse of what can be achieved in this area of using construction worker location for safety monitoring purposes. The research uncovered a strong enthusiasm from construction industry professionals to implement the proposed framework of location monitoring for safety, as well as other purposes.

7.6 Research Limitations

Saunders et al. (2009, p. 538) state that “*Virtually all research has its limitations*”. They state that limitations are inherent in research due to the methodological choices made, the nature, type and amount of data collected and the conclusions drawn from the analysis of the data. Saunders et al. (2009) caution that limitations must not be seen as confessions of weakness, rather that they are reflections of the degree to which the findings of a study may be considered the ‘*truth*’. The limitations in the conduct and findings of this thesis are discussed in the following sections.

7.6.1 Methodological Limitations

This thesis has limitations due to the methodological choices that were made in the conduct. For instance, the research was conducted under a qualitative paradigm. It is widely considered that results from qualitative studies are contextual in nature and there can be unintended consequences in generalising them for a global context (Yin, 2009). The framework to monitor the location of construction workers for safety purposes was

developed by conducting semi-structured interviews with site superintendents. This method of data collection has its deficiencies as there is a possibility of interviewer or interviewee bias (Saunders et al., 2009). Construction professionals that participated in this research were all from one geographic area in the United States. It is unclear how the results might be different if participants from other regions / cultures / countries had participated in the study. It is unknown how the implementation of the framework may differ in a different country with its own unique laws, regulations, culture, and construction industry hierarchy.

The framework was validated using an Internet survey of construction industry participants. The Internet survey approach also has its drawbacks since it is difficult to get a high response rate and also have a representative sample (Wright, 2005). Internet surveys also assume that respondents are paying careful attention to the words when answering the survey and as such it cannot be ascertained that it is in fact true. Survey respondents may also be under the impression of doing a favour to researcher and may provide what they perceive to be the answers the researcher is expecting (Wyse, 2012). The data collected in the qualitative and quantitative stages of the research represents a snapshot view of the participants' opinions regarding the issues identified in this thesis. It is impossible to predict how these opinions might vary in longitudinal study of using the framework on an actual construction site(s). It is unknown how the results might vary if a higher number of construction professionals had participated in this study.

7.6.2 Limitations due to Scope of Study

Apart from safety officers and construction superintendents, workers, designers, owners, etc. all play a key role in the safety outcomes of a project. Their participation in the study regarding the issues considered in this thesis may have influenced the evolution of the framework developed in this study. The demonstrator software was not used on an actual construction project. Using the software in a live construction site would reveal the usefulness of the proposed framework more accurately. The cost of implementing the framework was not considered in this research. An analysis of implementation costs would allow the reader to better understand the cost-benefit scenarios of the proposed framework. Detailed logistical aspects of implementing the framework on a construction

site such as ‘How are the tags distributed and collected back?’ ‘How is the data stored and retrieved?’ ‘How can RFID tag data be used for analysis, in the event of an actual safety incident’ ‘How are the readers moved on site as the job progresses?’ ‘How are safe and unsafe zones determined on the construction site?’ etc., were not considered in this thesis.

Issues concerning privacy of the RFID tag data were not considered in this thesis. There may be some reluctance on part of the workers to wear the RFID tags as well, as suggested by participants of the study. Ethical concerns regarding who has access to the RFID tag data, how long will the data be stored and how that data is to be used have not been fully explored. Morale of construction workers can be affected and have an adverse affect on safety if they perceive the proposed method of tracking as ‘big-brother’ technology; this issue has not been explored in this thesis. Field issues and contractual issues requiring all participants on the construction site to wear the tags have also not been addressed. The impact of introducing a technological solution to monitor worker location could impact how superintendents perform their walk-throughs and related tasks; however, those issues were not fully considered in this research.

7.6.3 Limitations due to Technological Choices

The proposed framework for worker location monitoring was presented using RFID as the basis for location tracking. There are other technologies available that are equally promising for tracking location of people in a physical space, such as Zigbee networks, WLAN and indoor GPS. This research did not consider those technologies since the focus of this research was using location monitoring of workers for making safety related decisions. However, it must be acknowledged that newer choices are continuing to emerge in sensing technologies and some may well be better suited than RFID for construction worker location monitoring, from a site safety perspective. The data captured in implementing the framework can be used for a number of purposes, as suggested by the participants. These additional uses of construction worker location tracking using the proposed framework were not addressed in this thesis.

The prototype created to implement the framework had limited functionality and was evaluated on a conjured site and not on a live construction project. The technology used

for creating the prototype was not robust and had a one-minute delay in showing the location of construction workers. Using the RSSI information to interpret the location of an RFID tag can be inaccurate due to reflection of radio waves.

7.6.4 Limitations of Location Monitoring for Safety Purposes

Literature has shown that numerous issues affect the safety outcomes on a construction site. These include the safety climate within the organisation, training provided to the workers, involvement of the design team in considering safety, supervision on the construction site, productivity expectations on a project, etc. While research has also shown that accidents occur when construction workers move about within the site, knowing the location workers on site alone is not enough information to suggest that a safety incident is imminent. Similarly, workers may need to move through different areas on the construction site to access materials and in and of itself cannot be considered an unsafe situation.

Location monitoring systems can identify situations when workers enter dangerous areas and allow the supervisory or safety personnel to intervene. However, a location monitoring system based on RFID & BIM is not enabled to show what the workers are doing, regardless of their location on site. Comments by participants in the survey also suggested that an implementation of the framework would not show what the workers are doing, but merely show where they are located within the construction site. Therefore, construction worker location-monitoring systems for safety purposes are inherently limited in capability, and cannot be considered as an exclusive measure to prevent accidents.

7.7 Future Research

This research has shown that construction superintendents have a need to know the location of construction workers within a site. Under several circumstances it is a necessity to know the location of workers for the site superintendent. This research presented a framework for monitoring the movement of construction workers using RFID and BIM for safety purposes. The framework was evaluated using a software prototype in a simulated indoor environment. Further studies must be conducted to implement the

proposed framework in a real world situation on a construction site. Commercial software allowing the integration of RFID and BIM may make it easier for construction companies to implement the proposed framework. No such solution currently exists on the market. The costs of implementing the proposed solution are currently unknown. Further investigations must be conducted to find an affordable price point and perform cost-benefit analysis for the construction companies to implement the proposed framework. Further research about the most appropriate technology to use for tracking workers in a dynamic environment such as a construction site must be explored. The proposed method of tracking workers using RFID and BIM may have other applications apart from safety, as suggested by the participants. An opportunity to investigate those additional uses exists.

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APPENDICES

APPENDIX – 4.1

Interview Questionnaire and Representative Comments

- 1. Describe a typical workday on a construction site from the site supervisor's point of view. What are your key responsibilities, as a site supervisor?**

“As the superintendent in charge, you are responsible for everything going on out there. So the traditional ones you’ve got schedule, quality, safety, budget and owner’s satisfaction.”

“Well duties are pretty simple: Cost and schedule are the main two and the top one is safety. I kind of run them all together. Those responsibilities come with a lot of a, b, c’s underneath that because of the many activities that are going on within a job-site.”

- 2. What are the various steps a construction company takes, to ensure a safe construction site?**

“Everything starts with training and it is continuous training. We do our own in house training. We are constantly updating our safety manual. Our safety program is more stringent than OSHA’s safety program.”

“Well, we have a safety manual and I am also OSHA 30-Hour certified that we have to keep up with it every 4 or 5 years. We have in-house safety seminars and webinars.”

3. How is this different from a site supervisor’s role in maintaining health safety of construction personnel on site?

“Safety is an all-day thing, watching what people are doing and making sure that they are doing it right at all times.”

“My number one goal in life has always been, as a superintendent that no one gets seriously injured or killed on a project that I’m managing”

4. How many times in a typical day do you walk the various locations within the construction site?

“The number of times I walk the site has a lot to do with the size of the job, but you walk the site first thing in the morning, right after break, right after lunch and the end of the day, so at least four times.”

“At a minimum we try to walk the jobsite in the morning, at noon and again late afternoon, so we can see how everybody is getting started out, at lunchtime to see how they are progressing and in the afternoon, to see how far they got done.”

5. How do you keep track of the location of various personnel, visitors, inspectors etc., on the construction site?

“We know where they should be based on the activities that are going on that day and also as we walk through the site.”

“Well, one thing, a lot of older guys like myself, we probably work from a feel or an instinct and we know where they are supposed to be. Of course I know schedule as well so I know what work is going on.”

6. Is it important for the site supervisor to know the location of various personnel within the construction site? What key decisions are made by site superintendent that depend on the location of personnel, visitors, inspectors etc., within the construction site?

“It is important information. I can’t accurately submit my daily report unless I know. It is very important for us to know exactly what’s going on job site. We gather this information by walking the job-site.”

“Yes it is very important to know. There is a lot of high-tech equipment on site and if a safety incident were to occur, I would like to know where everybody is at, in case I have to evacuate the site.”

- 7. Does it ever occur that there are too many people on the construction site, for the superintendent to know everyone’s location within the site at any given time? How does a superintendent handle the situation in such circumstances?**

“Ah yes. I’ve been on jobs twenty-eight story concrete frame hotels and we’ve had five hundred people on the job so therefore of course me as the primary superintendent, no I cannot know where everyone is. Of course you depend on the information you get from your own area superintendents and your subcontractors superintendents.”

“Absolutely it happens a lot. I cannot keep with where everybody is at all times, so it’s a struggle.”

- 8. Have there ever been safety incidents that could have been prevented had you been present at that location to oversee the progress of work? Can you give an example?**

“Absolutely, almost on a daily basis I see near miss accidents and I prevent them. I think all accidents are preventable. It’s really a mindset to do everything safely, my approach with all my employees, instead of hound dog them with rules or discipline them, and sometimes discipline is what it takes, but I try to get them to participate to be a team player and teach them to do it safely the first time.”

“Preventing near misses is a regular occurrence.”

- 9. How do you pay extra attention to the persons on site that you consider being within the vicinity of a dangerous situation, such as temporary shoring or high-**

rise construction or heavy machinery or even near misses?

“Of course we use barriers where it is applicable but we try to plan ahead. We try to communicate to people to where work is going on and where they are and where they are not supposed to be. If we find people in areas where they are not supposed to be, we go from enforcement to a disciplinary situation. Because you can’t just wait for people to get hurt and try to take care of them then.”

“First thing we do is a visual barricade, like fencing, control access points, flagmen and security guards.”

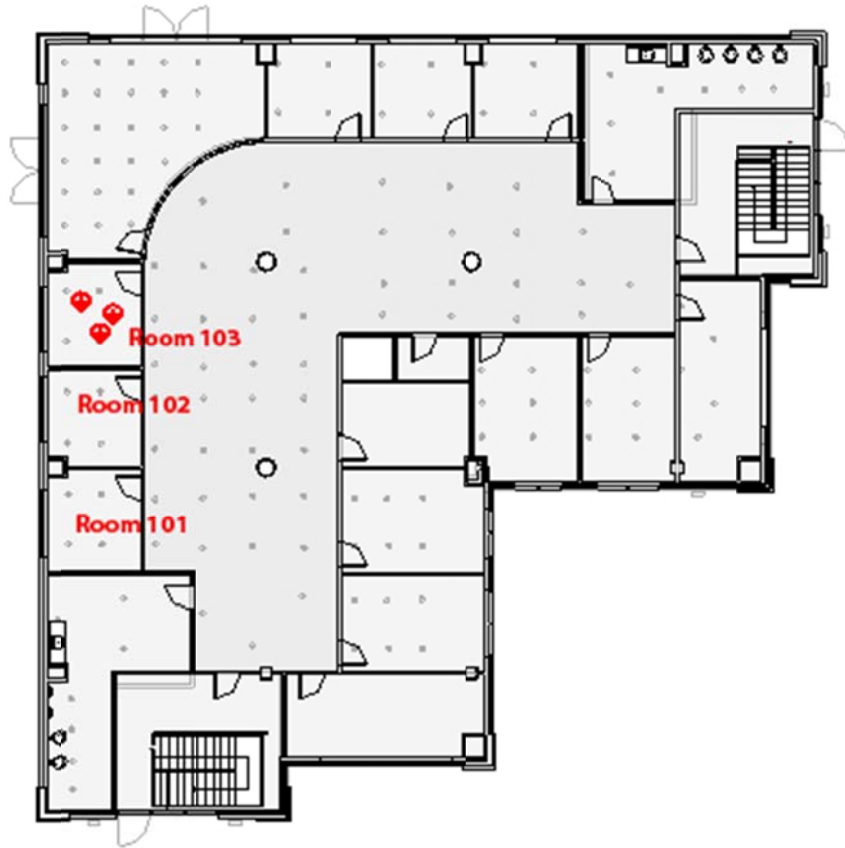
10. Would you use a mobile device that allows you to see the location of the various personnel within the construction site in a 3-D model?

“That could be beneficial, most especially on a larger job.”

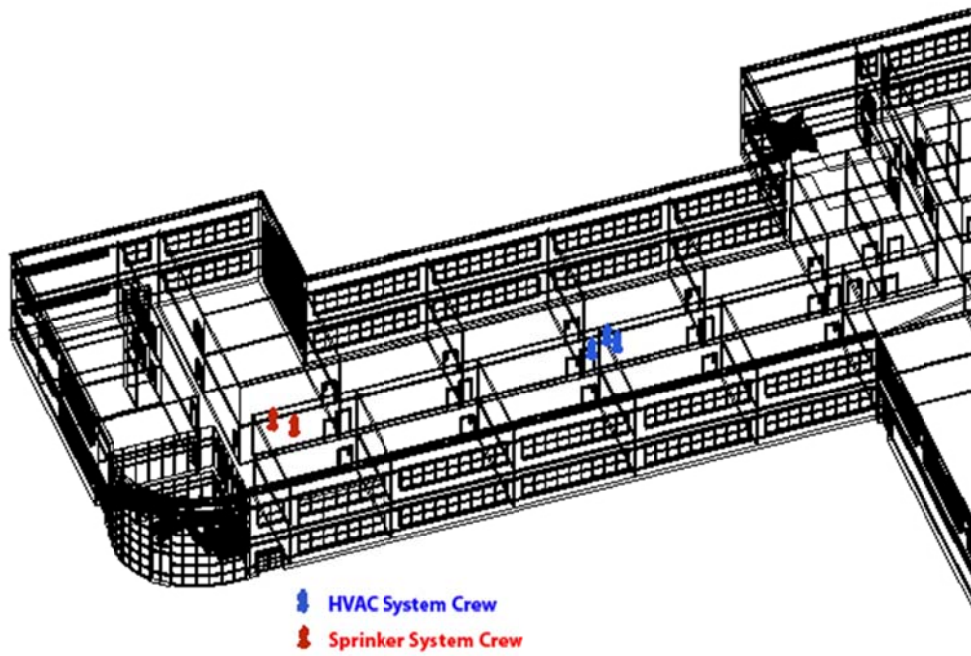
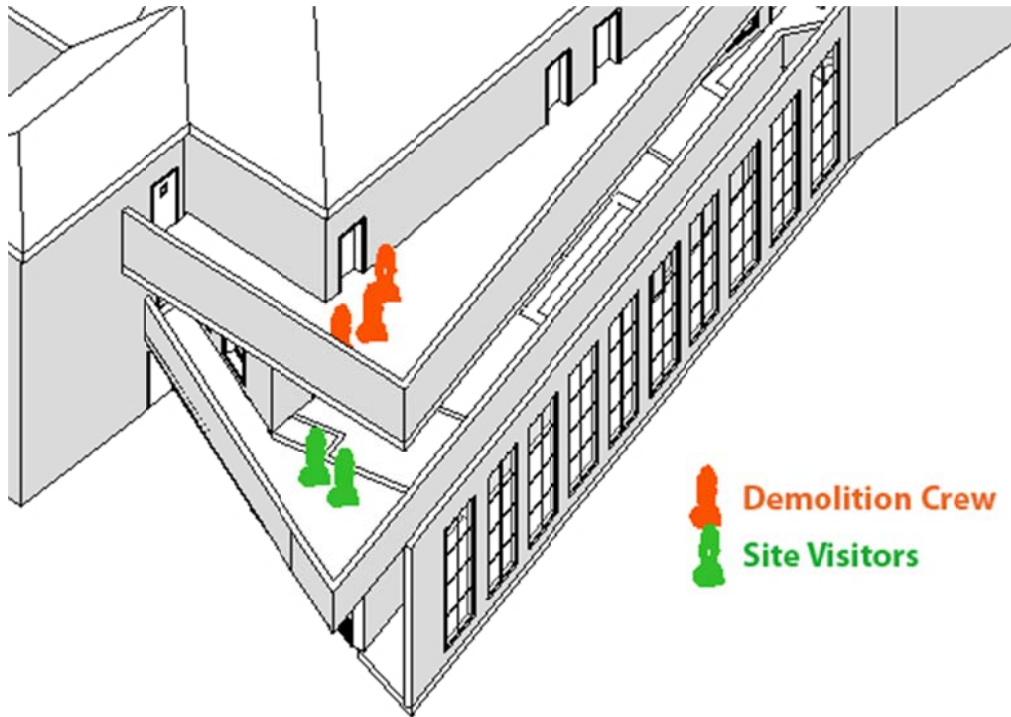
“I believe this could be useful. Especially for specific superintendents too, if you could colour code your people, and watch all of your areas simultaneously to see where people are, yeah I could see that being useful.”

APPENDIX – 4.2

Illustrations Shown to Construction Superintendents in Semi-Structured Interviews



Appendix – 4.2: Illustrations Shown to Construction Superintendents in Semi-Structured Interviews



APPENDIX – 5.1

Slides Used for Survey Video

A Framework to Monitor Movement
of Construction Workers using RFID &
BIM


Introduction

Supervision

Monitoring for Safety

Feedback from Superintendents

Technology for Monitoring Movement



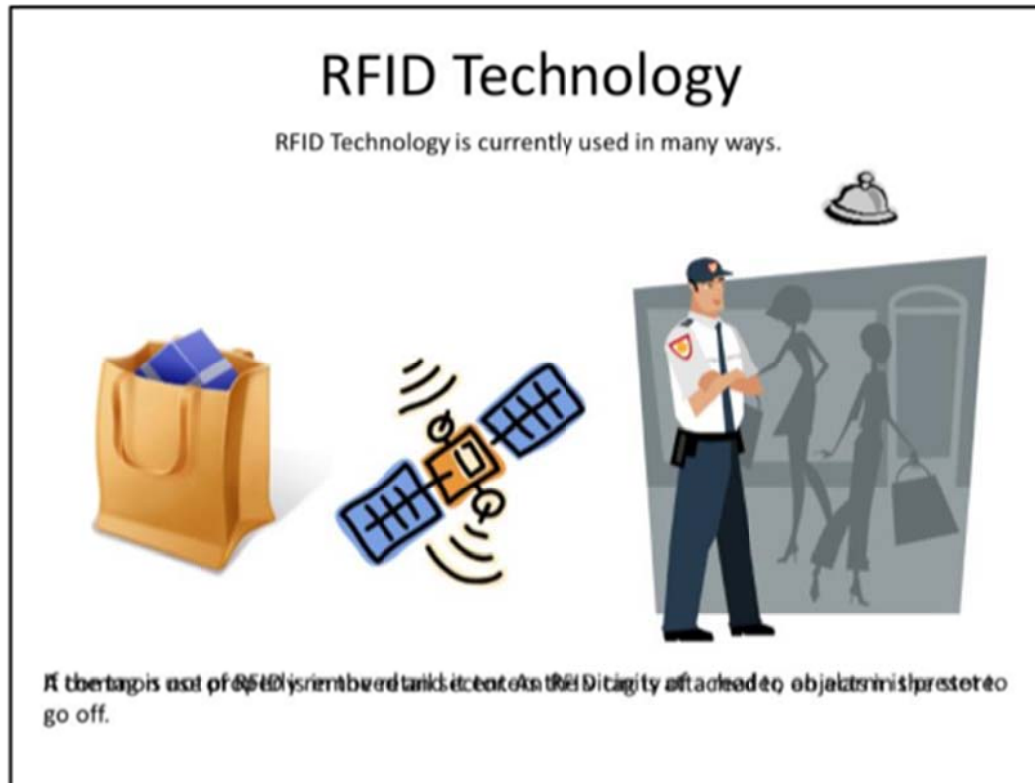
Superintendent plays a key role to maintain site safety

Monitoring is a key aspect of site superintendents' responsibilities.

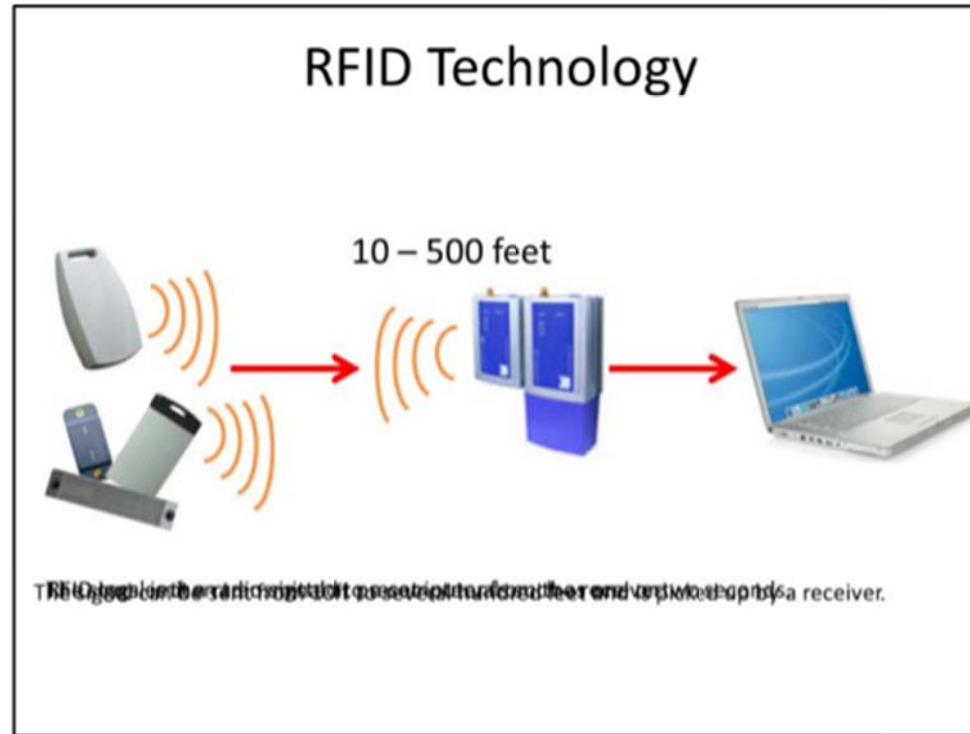
This allows the superintendent to monitor safe work procedures

This research is based on feedback from the construction industry.

The aim of this research is to assist the superintendent in maintaining a safe work environment using technological tools




RFID Technology is currently used in many ways. A common use is in the retail industry. An RFID tag is attached to objects in the store. If a tag is not been properly removed and it enters the vicinity of a reader, an alarm is preset to go off.



Active RFID tags send a radio signal that is picked up by a receiver. The signal can be sent from 10ft to several hundred feet. This signal can be transmitted to a computer from the receiver.

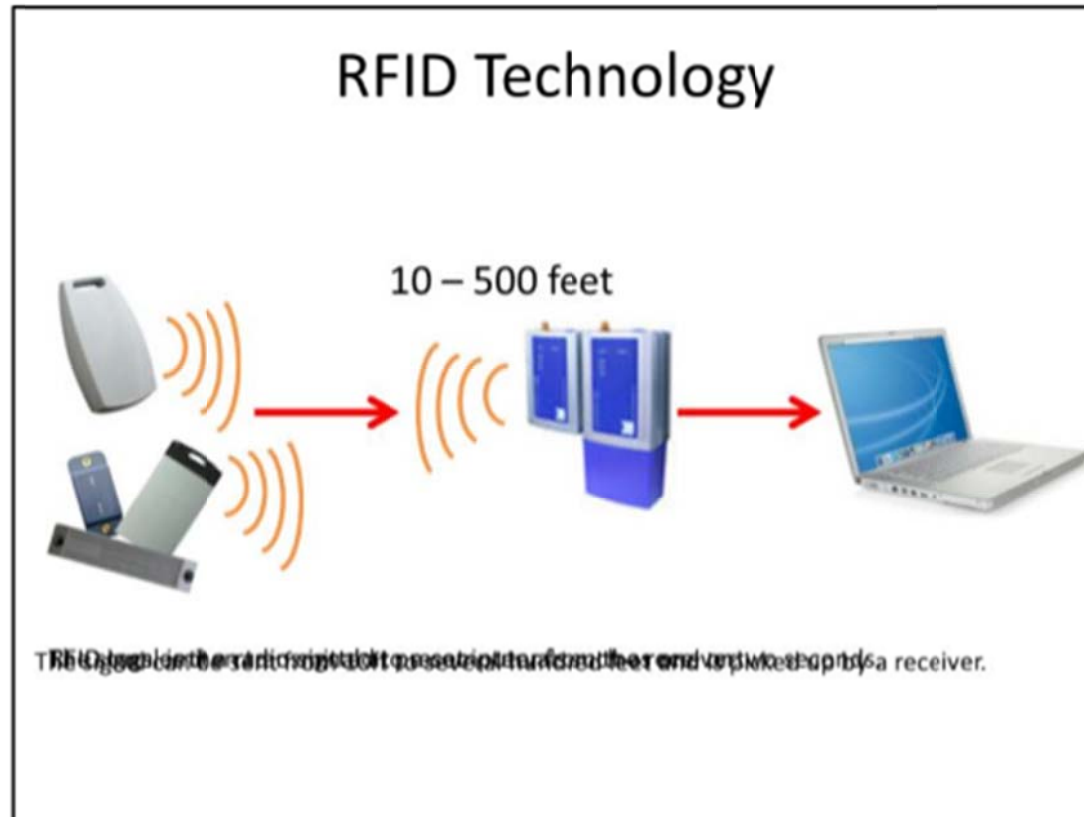
RFID for this Research



An RFID tag can be attached to a hard hat so that the worker wearing the hat can be electronically tracked.

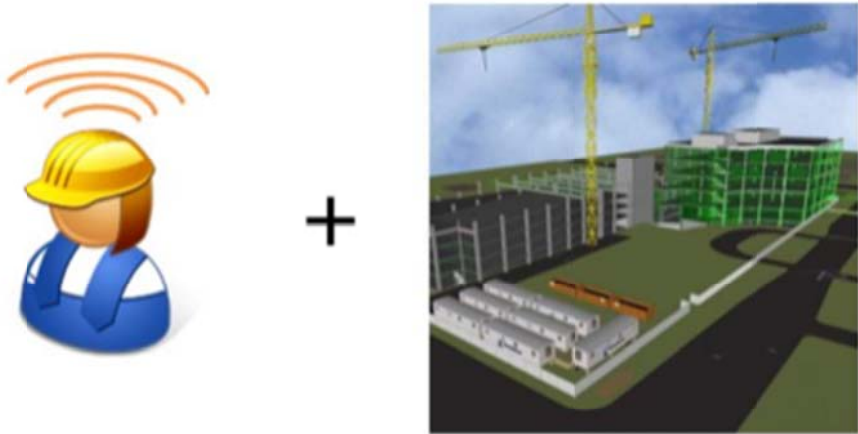
The diagram illustrates the concept of RFID tracking for a worker. It shows a yellow hard hat on the left, followed by a plus sign and a small grey RFID tag. This is followed by an equals sign and a worker wearing the yellow hard hat. Above the worker's head are several curved lines representing radio frequency signals, indicating that the worker is being tracked electronically.

An RFID tag can be attached to a hard hat so that a worker wearing the hard had can be electronically tracked.



Active RFID tags send a radio signal that is picked up by a receiver. The signal can be sent from 10ft to several hundred feet. This signal can be transmitted to a computer from the receiver.

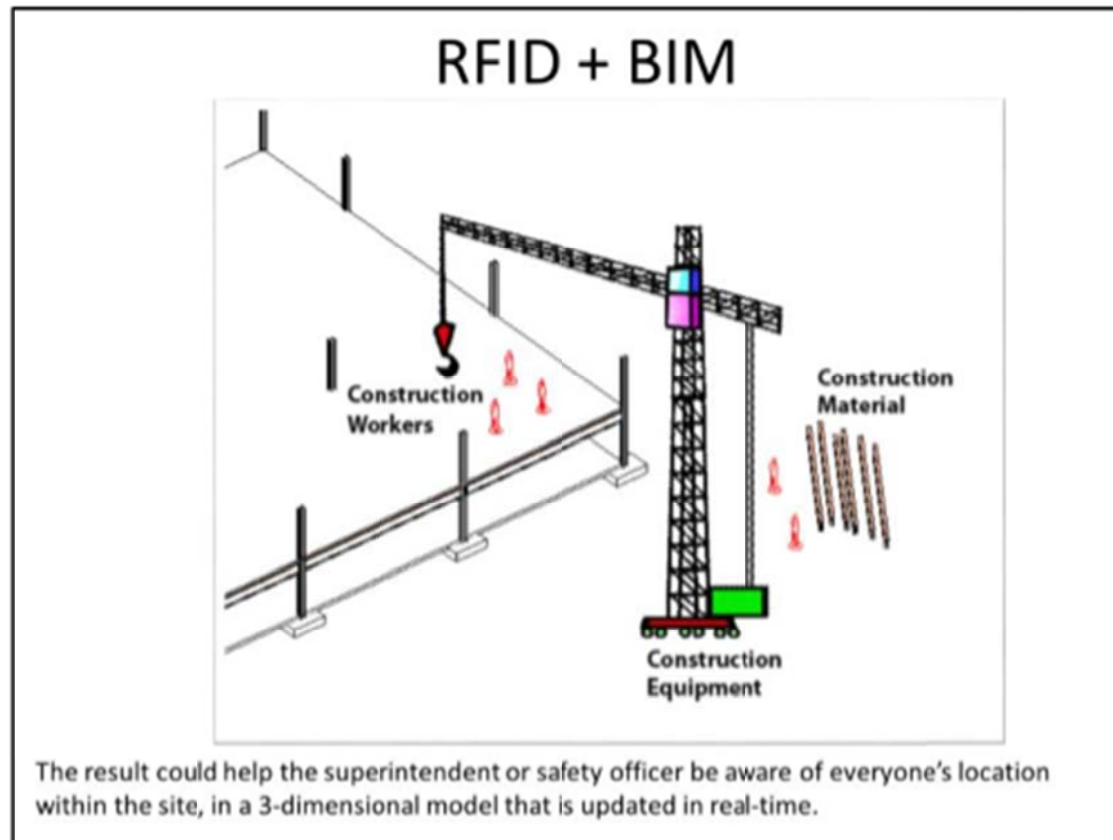
RFID + BIM



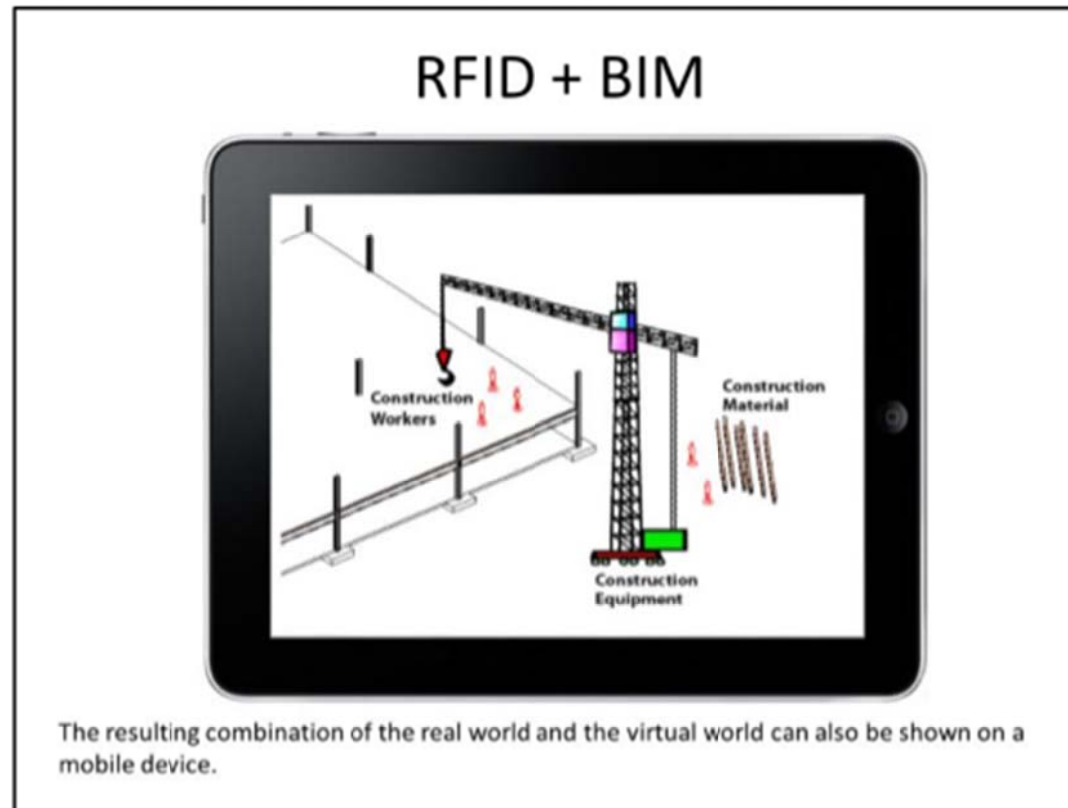
+

This research proposes to combine the location of the worker from RFID technology with a Building Information Model.

This research proposes to combine the location of the worker in a Building Information Model.



The result could help the superintendent or safety officer aware of everyone's location within the site, in a 3-dimensional model that is updated in real-time.



The resulting combination of the real world and the virtual world can be shown on a mobile device.

APPENDIX – 5.2
SURVEY SCREENS

Consent for Participation in Survey

**Topic: A Decision Support Framework for Site Monitoring using RFID
and BIM**

1. The purpose of this survey is to validate a conceptual framework to monitor construction worker safety within a jobsite by combining RFID technology with BIM technology.
2. There are 18 questions in this survey, presented in six sections, based on the context. It may take a maximum of 10 – 15 minutes of your time to complete the survey.
3. Your participation in this survey is completely voluntary. You may stop the survey at any time by closing this browser window and your data will not be used in compiling the results of the survey.
4. This is an anonymous survey. This survey does not seek any personal information about you or your company. Please do not provide any identifying information within your answers.
5. The information collected in this study will be disseminated only by using a summary of results from all participants.
6. This study has been approved by the 'University of Salford Research Ethics Panel'.
7. The author expresses sincere thanks to you for agreeing to spend your valuable time in answering this survey.

If you are satisfied with the above statements and agree to take part in the study, please click the 'Next' button below. If you are unwilling to participate in this study for any reason, please close this browser window.

Please Watch this Short Video about this Research



1. What is the size of your company (annual revenue)? **(required)**

Choose One ▼

2. What type of construction best describes your company (check all applicable options)? **(required)**

General Construction

Industrial Construction

Heavy Civil Construction

Specialty Construction

other

3. What is your current role in your company? **(required)**

Superintendent

Assistant Superintendent

Foreman

Project Manager

Assistant Project Manager

Safety Officer

Owner's Representative

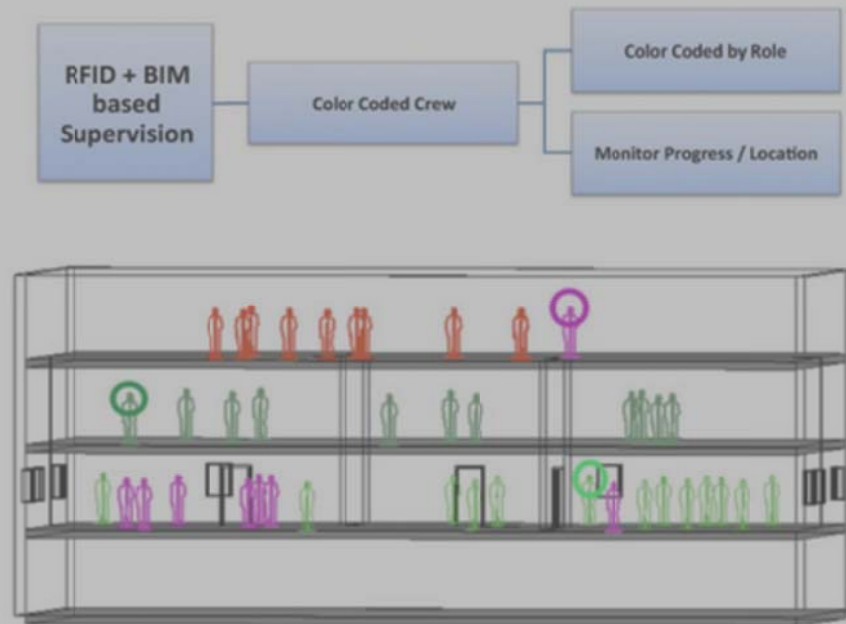
other

4. How many years have you been working in the construction industry? **(required)**

Choose One ▼

Section II: Color Coded Crews by Trade

By combining RFID with BIM, crewmembers can be shown by using distinct colors, based on their trade and highlight the location of the trade superintendent (*highlighted by the circles in the figure below*). This figure can quickly show the superintendent when there are congested areas or when workers are present in dangerous areas where they are not trained to be working. It can also be used to monitor the progress of construction.



Based on the above description for the application of RFID + BIM solution on a construction site, please rate the following statements:

5. "The tool described will facilitate the superintendent to see, in real time, color coded crew members at various locations within the jobsite." Please rate this statement. **(required)**

Choose One ▼

6. "The tool described will facilitate the superintendent to see, in real-time color coded crews by their role (example: a halo around the HVAC crew foreman) at various locations within jobsite." Please rate this statement. **(required)**

Choose One ▼

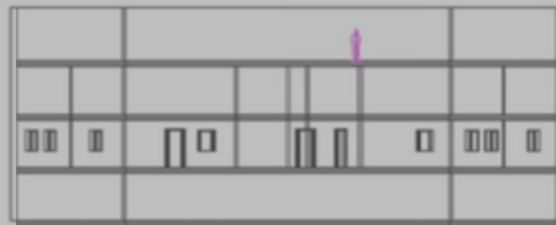
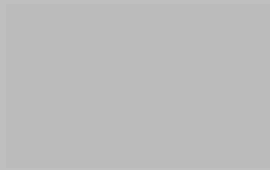
7. "The tool described provides the superintendent an **additional means** to estimate the progress of work, based on the location of the color coded crews" Please rate this statement. **(required)**

Choose One ▼

Additional Comments:

Section III: Emergency & Critical Situations

If an accident were to happen on a construction site, the superintendent starts the emergency action plan where all workers are required to come to a pre-decided muster point and begin the head count process. Using RFID and BIM combination the superintendent would be able to see the location of any workers missing or to ensure that everybody is present at the muster point (as illustrated in the figure below). By incorporating telecommunication services, an alert may be sent to the superintendent and/or worker when a person enters a dangerous area, further automating this process.



Based on the above description for the application of RFID + BIM solution on a construction site, please rate the following statements:

8. "A tool that shows the real-time location of workers on the site, during an emergency situation will assist the superintendent." **Please rate this statement. (required)**

Choose One ▼

9. "If a tool can send an automated alarm to a construction worker when he/she enters a forbidden area, it will facilitate the superintendent by acting as an **additional measure** to monitor safety" **Please rate this statement. (required)**

Choose One ▼

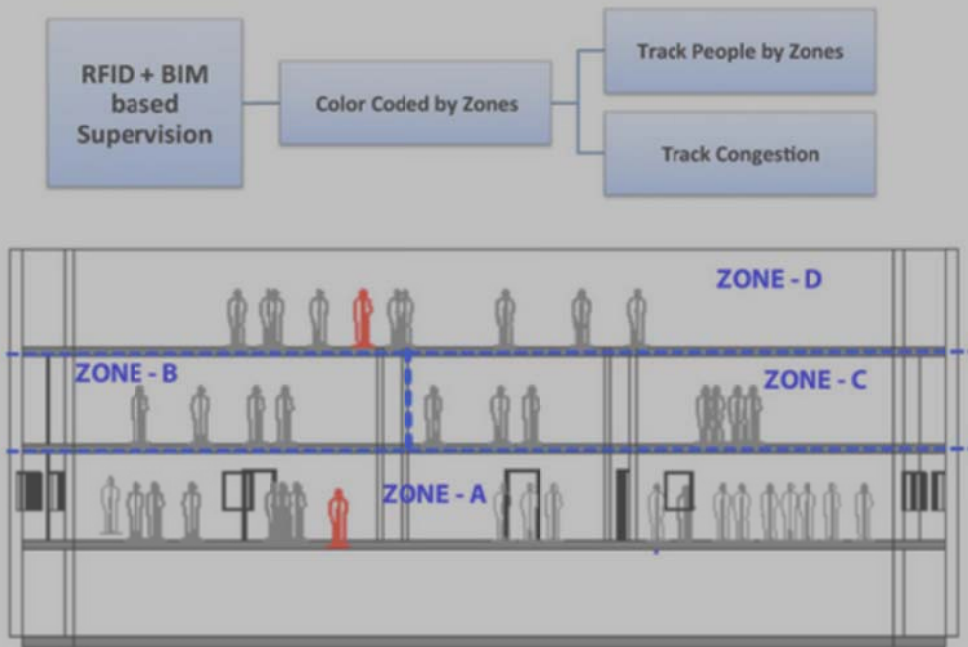
10. "A tool that can automate the head count process, in the event of an emergency situation on a construction site, will assist the superintendent." **Please rate this statement. (required)**

Choose One ▼

Additional Comments:

Section IV: Color Coded by Zones

A scenario in which workers can be tracked by color coded scheme, based on whether or not they are in the correct zone is proposed. Instead of the superintendent looking at all the workers and identifying if they are in the correct place, this process would split the jobsite into various zones and highlight anyone that is not in the correct zone, based on a previously decided scheme.



Based on the above description for the application of RFID + BIM solution on a construction site, please rate the following statements:

11. "A construction site may be divided into zones to allow the superintendent to track movement of workers within each zone, as shown in the figure above" Please rate this statement. **(required)**

Choose One ▼

12. "A tool that can highlight, in real-time, construction workers when they enter an unauthorized zone on the site, will facilitate the superintendent by acting as additional means to monitor site safety" Please rate this statement. **(required)**

Choose One ▼

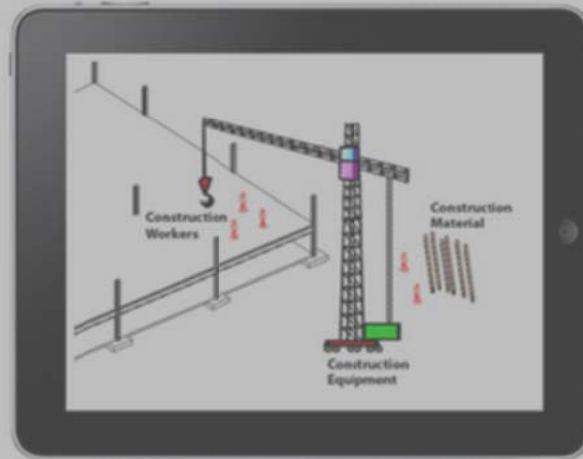
13. "The proposed tool will allow the superintendent, in real-time, to identify congested areas within the jobsite." Please rate this statement. **(required)**

Choose One ▼

Additional Comments:

Section V: Remote Management

The proposed solution can be used for remote management and provide some measure of oversight for the superintendent that cannot go to all areas of the jobsite. This can also be used for remotely monitoring the jobsite from the home office, if necessary. This solution can be used by the foreman, safety officers and others.



Based on the above description for the application of RFID + BIM solution on a construction site, please rate the following statements:

14. "If a superintendent is unable to physically be on the jobsite (E.g: attending a meeting), he/she will be facilitated by using the proposed tool to remotely monitor the jobsite in real-time" Please rate this statement. **(required)**

Choose One ▼

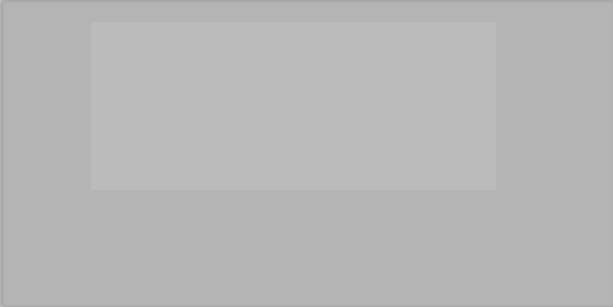
15. "Foremen and subcontractor superintendents will also be able to use the proposed tool to monitor the movement of their respective crew members within the jobsite." Please rate this statement. **(required)**

Choose One ▼

16. "The proposed tool will facilitate home office personnel to monitor the progress of construction on the jobsite." Please rate this statement. **(required)**

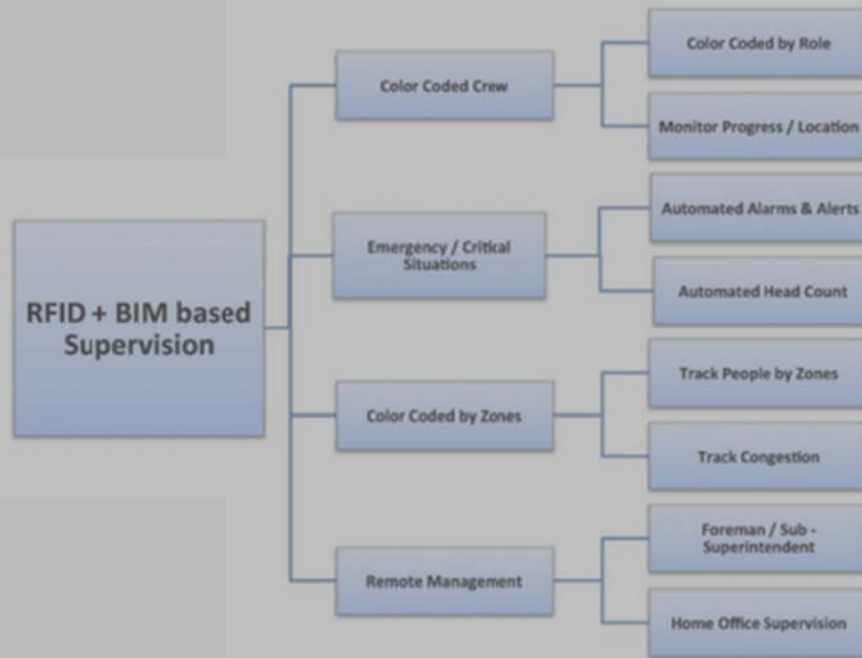
Choose One ▼

Additional Comments:



Section VI: Conclusion

A combination of BIM & RFID technologies is proposed to track the movement of construction workers within a site. The conceptual framework has four scenarios by which safety on construction sites may be monitored by site superintendents, as shown below.



Based on the above description for the application of RFID + BIM solution on a construction site, please rate the following statement and please provide your concluding thoughts:

17. "The proposed tool is an **additional means** to facilitate superintendents to monitor the health & safety of construction workers on a jobsite". Please rate this statement. **(required)**

Choose One ▼

18. Please provide your concluding thoughts, views and any other suggestions about the proposed solution of combining RFID and BIM to monitor safety of construction workers on the jobsite.

APPENDIX – 6.1

VBA Code used with Microsoft Excel

```
Attribute VB_Name = "Module1"
Dim TimetoRun
```

```
Function Start_Import()
```

```
TimetoRun = Now + TimeValue("00:01:00")
```

```
Application.OnTime TimetoRun, "PasteData"
```

```
End Function
```

```
Function LatestLog(Location As String) As String
Attribute LatestLog.VB_ProcData.VB_Invoke_Func = "\n14"
```

```
'
' Get the Last Modified ILR Log File
'
```

```
Dim FileSys As Object
Dim objFile As Object
Dim myFolder
Dim strFilename As String
Dim dteFile As Date
```

```
'set path for files - change for your folder
'Set const on next line to your folder path
```

```
'set up filesys objects
Set FileSys = CreateObject("Scripting.FileSystemObject")
Set myFolder = FileSys.GetFolder(Location)
```

```
'loop through each file and get date last modified. If largest date then store Filename
```

```
dteFile = DateSerial(1900, 1, 1)
For Each objFile In myFolder.Files
    'Debug.Print objFile.Name
    If InStr(1, objFile.Name, ".csv") > 0 Then
        If objFile.DateLastModified > dteFile Then
            dteFile = objFile.DateLastModified
```



```

        strFilename = objFile.Name
    End If
End If
Next objFile

LatestLog = strFilename

Set FileSys = Nothing
Set myFolder = Nothing

End Function

Attribute VB_Name = "Module2"
Sub PasteData()
'
' PasteData Macro
'
Application.ScreenUpdating = False

Dim qstr As String

Set wbOOR = Application.Workbooks("Import_Excel_Data.xlsm")
Sheets("Data").Select
Range("A:E").Clear
Range("A1").Select

qstr = "TEXT;C:\Users\Administrator\Documents\ILR Logs\" &
LatestLog("C:\Users\Administrator\Documents\ILR Logs")

With ActiveSheet.QueryTables.Add(Connection:=qstr, Destination:=Range("$A$1"))
    .Name = "Test"
    .FieldNames = True
    .RowNumbers = False
    .FillAdjacentFormulas = False
    .PreserveFormatting = True
    .RefreshOnFileOpen = False
    .RefreshStyle = xlInsertDeleteCells
    .SavePassword = False
    .SaveData = True
    .AdjustColumnWidth = True
    .RefreshPeriod = 0
    .TextFilePromptOnRefresh = False
    .TextFilePlatform = 437

```

```
.TextFileStartRow = 1
.TextFileParseType = xlDelimited
.TextFileTextQualifier = xlTextQualifierDoubleQuote
.TextFileConsecutiveDelimiter = False
.TextFileTabDelimiter = True
.TextFileSemicolonDelimiter = False
.TextFileCommaDelimiter = True
.TextFileSpaceDelimiter = False
.TextFileColumnDataTypes = Array(1, 1, 1, 1, 1)
.TextFileTrailingMinusNumbers = True
.Refresh BackgroundQuery:=False
End With
```

```
Range("C:C").Select
Selection.NumberFormat = "h:mm:ss"
```

```
Sheets("Calculations").Select
Range("A1").Select
```

```
Worksheets("Calculations").Calculate
Call Start_Import
```

```
ThisWorkbook.Save
```

```
Application.ScreenUpdating = True
```

```
Call sendEmergencyMail
```

```
End Sub
```

```
Attribute VB_Name = "Module3"
Sub Auto_Open()
```

```
Application.Run ("PasteData")
Call Start_Import
```

```
End Sub
```

```
Sub Auto_Close()
```

```
Application.OnTime TimetoRun, "PasteData", False
```

```
End Sub
```

```
Sub SendAlert(workerid As String)
```

```

'Setting up the Excel variables.
Dim olApp As Object
Dim olMailItm As Object
Dim iCounter As Integer
Dim Dest As Variant
Dim SDest As String

'Create the Outlook application and the empty email.
Set olApp = CreateObject("Outlook.Application")
Set olMailItm = olApp.CreateItem(0)

'Using the email send an alert.
With olMailItm

    .BCC = workerid
    .Subject = "Danger!"
    .Body = "Danger!!! You have entered an unauthorised zone!!! -Anoop"
    .Send
End With

'Clean up the Outlook application.
Set olMailItm = Nothing
Set olApp = Nothing
End Sub

Sub sendEmergencyMail()

Sheets("Summary").Activate

For iCounter = 1 To WorksheetFunction.CountA(Columns(1))
    If (Cells(iCounter, 6).Value = "1") Then
        Call SendAlert(Cells(iCounter, 13).Value)
    Else
        ' SDest = SDest & ";" & Cells(iCounter, 12).Value
    End If
Next iCounter

End Sub

```

APPENDIX – 6.2**C# Code using Tekla Structures API**

```
using System;
using System.Collections.Generic;
using System.Linq;
using System.Threading.Tasks;
using System.Windows.Forms;
using DrawWorkers;

namespace DrawWorkers
{
    static class DrwWrksPrgm
    {
        /// <summary>
        /// The main entry point for the application.
        /// </summary>
        [STAThread]
        static void Main()
        {
            Application.EnableVisualStyles();
            Application.SetCompatibleTextRenderingDefault(false);
            Application.Run(new DrawWorkers.SafetyMonitoring());
        }
    }
}
```

```
namespace DrawWorkers
{
    partial class SafetyMonitoring
    {
        /// <summary>
        /// Required designer variable.
        /// </summary>
        private System.ComponentModel.IContainer components = null;

        /// <summary>
        /// Clean up any resources being used.
        /// </summary>
        /// <param name="disposing">true if managed resources should be disposed; otherwise, false.</param>
        protected override void Dispose(bool disposing)
        {
            if (disposing && (components != null))
            {
                components.Dispose();
            }
            base.Dispose(disposing);
        }

        #region Windows Form Designer generated code

        /// <summary>
        /// Required method for Designer support - do not modify
        /// the contents of this method with the code editor.
        /// </summary>
        private void InitializeComponent()
        {

```

```
this.WrksByTrade_Button = new System.Windows.Forms.Button();
this.WrksByZone_Button = new System.Windows.Forms.Button();
this.button1 = new System.Windows.Forms.Button();
this.button2 = new System.Windows.Forms.Button();
this.SuspendLayout();
//
// WrksByTrade_Button
//
this.WrksByTrade_Button.Location = new System.Drawing.Point(73, 12);
this.WrksByTrade_Button.Name = "WrksByTrade_Button";
this.WrksByTrade_Button.Size = new System.Drawing.Size(131, 38);
this.WrksByTrade_Button.TabIndex = 0;
this.WrksByTrade_Button.Text = "Track Workers by Trade";
this.WrksByTrade_Button.UseVisualStyleBackColor = true;
this.WrksByTrade_Button.Click += new System.EventHandler(this.DrawByTradeButton);
//
// WrksByZone_Button
//
this.WrksByZone_Button.Location = new System.Drawing.Point(73, 78);
this.WrksByZone_Button.Name = "WrksByZone_Button";
this.WrksByZone_Button.Size = new System.Drawing.Size(131, 38);
this.WrksByZone_Button.TabIndex = 1;
this.WrksByZone_Button.Text = "Track Workers by Zone";
this.WrksByZone_Button.UseVisualStyleBackColor = true;
this.WrksByZone_Button.Click += new System.EventHandler(this.DrawByZoneButton);
//
// button1
//
this.button1.Location = new System.Drawing.Point(73, 198);
this.button1.Name = "button1";
```

```

this.button1.Size = new System.Drawing.Size(131, 34);
this.button1.TabIndex = 2;
this.button1.Text = "Show Congested";
this.button1.UseVisualStyleBackColor = true;
this.button1.Click += new System.EventHandler(this.CongestedButton);
//
// button2
//
this.button2.Location = new System.Drawing.Point(73, 142);
this.button2.Name = "button2";
this.button2.Size = new System.Drawing.Size(130, 31);
this.button2.TabIndex = 3;
this.button2.Text = "Save Model to Web";
this.button2.UseVisualStyleBackColor = true;
this.button2.Click += new System.EventHandler(this.SaveModelToWebButton);
//
// SafetyMonitoring
//
this.AutoScaleDimensions = new System.Drawing.SizeF(6F, 13F);
this.AutoScaleMode = System.Windows.Forms.AutoScaleMode.Font;
this.ClientSize = new System.Drawing.Size(284, 262);
this.Controls.Add(this.button2);
this.Controls.Add(this.button1);
this.Controls.Add(this.WrksByZone_Button);
this.Controls.Add(this.WrksByTrade_Button);
this.Name = "SafetyMonitoring";
this.Text = "RFID + BIM Safety Monitoring";
this.ResumeLayout(false);
}

```

```
#endregion

private System.Windows.Forms.Button WrksByTrade_Button;
private System.Windows.Forms.Button WrksByZone_Button;
private System.Windows.Forms.Button button1;
private System.Windows.Forms.Button button2;
}
}

using System;
using System.Data;
using System.Data.Common;
using System.IO;
using System.Windows.Forms;
using Tekla.Structures.Dialog;
using System.Collections;
using System.Diagnostics;
using System.Globalization;
using Microsoft.Office.Core;
using Excel = Microsoft.Office.Interop.Excel;
using Tekla.Structures.Model;
using Tekla.Structures.Model.UI;
using Tekla.Structures.Geometry3d;
using Tekla.Structures.Model.Operations;
```



```
namespace DrawWorkers
{
    public partial class SafetyMonitoring : Form
    {
        #region Private Properties

        private Model _model;

        public Model Model
        {
            get { return _model ?? (_model = new Model()); }
            set { _model = value; }
        }
        #endregion

        public SafetyMonitoring()
        {
            InitializeComponent();
        }

        private void DrawByTradeButton(object sender, EventArgs e)
        {
            if (!Model.GetConnectionStatus())
            {
                MessageBox.Show("Tekla Structures Not Connected");
                return;
            }
        }
    }
}
```

```
    }  
  
    RemoveMen();  
  
    DrawAllWorkersbyTrade();  
  
    Model.CommitChanges();  
  
    ViewHandler.SetRepresentation("standard");  
  
    ModelViewEnumerator viewEnum = ViewHandler.GetAllViews();  
  
    while (viewEnum.MoveNext())  
    {  
        Tekla.Structures.Model.UI.View theView = viewEnum.Current;  
  
        if (theView.Name == "3d")  
        {  
            ViewHandler.RedrawView(theView);  
        }  
    }  
}  
  
public void DrawAllWorkersbyTrade()  
{  
    Excel.Application app = new Microsoft.Office.Interop.Excel.Application();
```

```

Excel.Workbook workbook = app.Workbooks.Open(@"C:\Users\Administrator\Documents\Data\Import_Excel_Data.xlsm");
Excel._Worksheet wk = (Excel.Worksheet)workbook.Worksheets.get_Item(1);
wk.Activate();

int rcount = wk.UsedRange.Rows.Count;

int i = 2;
while (i <= rcount)
{
    var p1xCell = (Excel.Range)wk.Cells[i, 2];
    double p1x = Convert.ToDouble (p1xCell.Value);
    var p1yCell = (Excel.Range)wk.Cells[i, 3];
    double p1y = Convert.ToDouble (p1yCell.Value);

    var workerClassCell = (Excel.Range)wk.Cells[i, 5];
    string workerClass = Convert.ToString (workerClassCell.Value);

    var workerNameCell = (Excel.Range)wk.Cells[i, 1];
    string workerName = Convert.ToString (workerNameCell.Value);

    Point point = new Point(p1x, p1y, 0.0);
    Point point2 = new Point(p1x + 350.0, p1y, 0.0);
    Beam beam = new Beam();
    beam.StartPoint = point;
    beam.EndPoint = point2;
    beam.Profile.ProfileString = "XMAN";
    beam.Class = workerClass;
    beam.Name = workerName;
    beam.Finish = "PAINT";
    beam.StartPointOffset = new Offset();
}

```

```
beam.EndPointOffset = new Offset();
bool result = false;
result = beam.Insert();

    i++;
}

workbook.Close(true);
}

private void DrawByZoneButton(object sender, EventArgs e)
{
    if (!Model.GetConnectionStatus())
    {
        MessageBox.Show("Tekla Structures Not Connected");
        return;
    }

    RemoveMen();

    DrawAllWorkersbyZone();

    Model.CommitChanges();

    ViewHandler.SetRepresentation("standard");
}
```

```
ModelViewEnumerator viewEnum = ViewHandler.GetAllViews();

while (viewEnum.MoveNext())
{
    Tekla.Structures.Model.UI.View theView = viewEnum.Current;

    if (theView.Name == "3d")
    {
        ViewHandler.RedrawView(theView);
    }
}

}

public void RemoveMen()
{

    if (!Model.GetConnectionStatus()) return;

    ModelObjectEnumerator enumerator = Model.GetModelObjectSelector().GetObjectsByFilterName("myFilter1");
    enumerator.SelectInstances = true;

    while (enumerator.MoveNext())
    {
        Beam myBeam = enumerator.Current as Beam;
    }
}
```

```

        myBeam.Delete();
    }
}

public void DrawAllWorkersbyZone()
{
    Excel.Application app = new Microsoft.Office.Interop.Excel.Application();
    Excel.Workbook workbook = app.Workbooks.Open(@"C:\Users\Administrator\Documents\Data\Import_Excel_Data.xlsm");
    Excel._Worksheet wk = (Excel.Worksheet)workbook.Worksheets.get_Item(2);
    wk.Activate();

    int rcount = wk.UsedRange.Rows.Count;

    int i = 2;
    while (i <= rcount)
    {
        var p1xCeIl = (Excel.Range)wk.Cells[i, 2];
        double p1x = Convert.ToDouble(p1xCeIl.Value);
        var p1yCeIl = (Excel.Range)wk.Cells[i, 3];
        double p1y = Convert.ToDouble(p1yCeIl.Value);

        var workerClassCeIl = (Excel.Range)wk.Cells[i, 5];
        string workerClass = Convert.ToString(workerClassCeIl.Value);

        var workerNameCeIl = (Excel.Range)wk.Cells[i, 1];
        string workerName = Convert.ToString(workerNameCeIl.Value);

        Point point = new Point(p1x, p1y, 0.0);
        Point point2 = new Point(p1x + 350.0, p1y, 0.0);
        Beam beam = new Beam();
    }
}

```

```
beam.StartPoint = point;
beam.EndPoint = point2;
beam.Profile.ProfileString = "XMAN";
beam.Class = workerClass;
beam.Name = workerName;
beam.Finish = "PAINT";
beam.StartPointOffset = new Offset();
beam.EndPointOffset = new Offset();
bool result = false;
result = beam.Insert();

    i++;
}

workbook.Close(true);
}

public void SavetoWeb()
{
    bool webmodel = Tekla.Structures.Model.Operations.Operation.SaveAsWebModel(@"C:\Users\Administrator\Desktop\Test");
}

private void CongestedButton(object sender, EventArgs e)
{
    if (!Model.GetConnectionStatus())
    {
        MessageBox.Show("Tekla Structures Not Connected");
    }
}
```

```
        return;  
    }  
  
    RemoveMen();  
    ShowCongested();  
    Model.CommitChanges();  
    ViewHandler.SetRepresentation("standard");  
    ModelViewEnumerator viewEnum = ViewHandler.GetAllViews();  
    while (viewEnum.MoveNext())  
    {  
        Tekla.Structures.Model.UI.View theView = viewEnum.Current;  
  
        if (theView.Name == "3d")  
        {  
            ViewHandler.RedrawView(theView);  
        }  
    }  
}  
  
public void ShowCongested()
```



```
{
    Excel.Application app = new Microsoft.Office.Interop.Excel.Application();
    Excel.Workbook workbook = app.Workbooks.Open(@"C:\Users\Administrator\Documents\Data\Import_Excel_Data.xlsm");
    Excel._Worksheet wk = (Excel.Worksheet)workbook.Worksheets.get_Item(2);
    wk.Activate();

    int rcount = wk.UsedRange.Rows.Count;

    String Congested;

    var congestedCell = (Excel.Range)wk.Cells[1, 8];
    Congested = Convert.ToString(congestedCell.Value);

    MessageBox.Show(Congested);

    int i = 2;
    while (i <= rcount)
    {
        var p1xCeIl = (Excel.Range)wk.Cells[i, 2];
        double p1x = Convert.ToDouble(p1xCeIl.Value);
        var p1yCeIl = (Excel.Range)wk.Cells[i, 3];
        double p1y = Convert.ToDouble(p1yCeIl.Value);

        var workerClassCeIl = (Excel.Range)wk.Cells[i, 5];
        string workerClass = Convert.ToString(workerClassCeIl.Value);

        var workerNameCeIl = (Excel.Range)wk.Cells[i, 1];
        string workerName = Convert.ToString(workerNameCeIl.Value);
    }
}
```

```
Point point = new Point(p1x, p1y, 0.0);
Point point2 = new Point(p1x + 350.0, p1y, 0.0);
Beam beam = new Beam();
beam.StartPoint = point;
beam.EndPoint = point2;
beam.Profile.ProfileString = "XMAN";

if (Congested == "CONGESTED")
{
    beam.Class = "2";
}
else
{
    beam.Class = workerClass;
}

beam.Name = workerName;
beam.Finish = "PAINT";
beam.StartPointOffset = new Offset();
beam.EndPointOffset = new Offset();
bool result = false;
result = beam.Insert();

i++;
}

}

private void SaveModelToWebButton(object sender, EventArgs e)
{
```

```
if (!Model.GetConnectionStatus())
{
    MessageBox.Show("Tekla Structures Not Connected");
    return;
}

SavetoWeb();

Model.CommitChanges();

ViewHandler.SetRepresentation("standard");

ModelViewEnumerator viewEnum = ViewHandler.GetAllViews();

while (viewEnum.MoveNext())
{
    Tekla.Structures.Model.UI.View theView = viewEnum.Current;

    if (theView.Name == "3d")
    {
        ViewHandler.RedrawView(theView);
    }
}
}
```