# 3D/4D BIM-Based Hazard Identification, Safety Regulations and Safety Monitoring of Construction Projects in Pre-construction and Construction Phases

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# ABSTRACT


Research studies indicate that construction industry is known as one of the most hazardous working around the world. Fatalities and injuries are the sad reality in construction industry and occur on construction site every day. In comparison with different industries, the risk of fatality or injury at work in construction sector is significantly greater than in others. They happen due to lack of safety planning, traditional methods and failure to follow the construction safety rules and regulations during a construction process.

In the recent years variety of approaches like Building Information Modeling (BIM) and innovation technologies such as Sensors, Global Position System (GPS), Ultra-Wide band (UWB), Game Technology, Laser Scan, Unmanned Aerial Vehicle (UAS) etc. have been developed to achieve benefits in design-for-safety or safety performance and improve construction safety. A large number of researchers attempt to integrate innovative technologies with safety as an efficient solution to prevent construction fatalities accidents and enhance health and safety in construction industry.

The applications of BIM in construction are growing rapidly. The utilization of BIM and visualizations tools can result in promoted safety performance by allowing design team members and managers to visually assess work environment situations and detect hazards situations. By using 3D/4D models, the project team members can communicate more effectively during a safety plan.

This study present a framework for Construction Project Progress Safety Monitoring. The framework consists of five stages. During the design stage, this system with the help of 3D software and BIM is capable of identifying potential hazards. In other words, the system make use of the gleaned information to prevent the likely hazards. In control phase, the Unmanned Aerial System (UAS) gives possibility of these rule's monitoring and control. The study indicates that integration of 3D BIM-based models and UAS technology have the potential to improve the identification, implementation and monitoring of field safety and increase the construction projects stakeholders' safety.

In conclusion, this thesis aims to increase health and safety in construction by integrating BIM and innovative technologies from design to implementation. Also this study attempts to prevent accidents before happening to decrease rate of fatalities and injuries in the construction sector.

**Keywords**: Building Information Modeling, Unmanned Aerial System, hazard identification, safety regulation, safety monitoring

# ÖZ

Araştırmalar, inşaat sektöründe yapılan işlerin dünyada en tehlikeli işlerden biri olarak kabul edildiğini göstermektedir. Ölümler ve yaralanmalar inşaat sektörünün üzücü gerçekleridir ve her gün şantiyelerde bu tür olaylar meydana gelmektedir. Değişik sektörler ile karşılaştırıldığında, inşaat sektöründe ölüm riski ya da yaralanma riski diğerlerine göre önemli ölçüde daha fazladır. Tüm bu kazalar, güvenlik planlaması eksikliği, geleneksel yöntemler ve yapım süresince güvenlik kuralları ve düzenlemelerine uyulmaması nedeniyle gerçekleşmektedir.

Son yıllarda, Yapı Bilgi Modellemesi (YBM) gibi değişik yaklaşımlar ve Kablosuz Sensörler, Küresel Konumlama Sistemi (KKS), Ultra-Geniş Bant (UGB), Oyun Teknolojisi, Lazer Tarayıcı (LT) ve İnsansız Hava Sistemi (İHS) v.b inovasyon teknolojileri tasarım-için-güvenlik veya güvenlik performans yararları elde etmek ve inşaat güvenliğini artırmak için geliştirilmiştir. Birçok sayıda araştırmacı, inşaatlardaki ölümlü kazaları önlemek ve inşaat sektöründe sağlık ve güvenliği artırmak için etkili bir çözüm olarak güvenlik ile inovatif teknolojileri entegre etmeye çalışmaktadır.

Yapımda YBM uygulamaları hızla artmaktadır. YBM ve görsel araçların kullanımı çalışma ortamı durumları değerlendirme ve tehlikeli durumları tespit etmede tasarım ekibi üyeleri ve yöneticilerine olanak vererek  artırılmış güvenlik performansını sağlayabilir. 3B / 4B modelleri kullanarak, proje ekip üyeleri güvenlik planı süresince daha etkili iletişim kurabilirler.

Bu çalışma İnşaat Proje İlerleme Güvenliğinin İzlenmesi için bir çerçeve sunmaktadır. Çerçeve beş aşamadan oluşmaktadır. Tasarım aşamasında, bu sistem 3B yazılım ve YBM yardımı ile potansiyel tehlikeleri belirleme yeteneğine sahiptir. Diğer bir deyişle, sistem olası tehlikeleri önlemek için toplanan bilgileri kullanır. Kontrol aşamasında, İnsansız Hava Sistemi (İHS) bu kuralları izleme ve kontrol imkanı verir. Çalışma, 3B YBM tabanlı modeller ve İHS teknolojisinin entegrasyonu saha güvenliğinin belirlenmesi, uygulanması ve izlenmesini geliştirmek ve inşaat projelerindeki paydaşların güvenliğini artırmak için potansiyele sahip olduğunu göstermektedir.

Sonuç olarak, bu tez tasarımdan uygulama aşamasına kadar YBM ve inovasyon teknolojilerini entegre ederek inşaat sağlığı ve güvenliğini artırmayı hedeflemektedir. Ayrıca bu çalışma, inşaat sektöründe gerçekleşen kazaları önlemek, ölüm ve yaralanma oranını azaltmak için girişimde bulunmaktadır.

**Anahtar kelimeler**: Yapı Bilgi Modellemesi, İnsansız Hava Sistemi, tehlike tanımlama, güvenlik düzenlemeleri, güvenlik izleme

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| | |
|---|---|
| BIM | Building Information Modelling |
| CAD | Computer Aid Design |
| PtD | Prevention through Design |
| AEC | Architectural Engineering Construction |
| UAS | Unmanned Aerial System |
| LS | Laser Scan |
| OSHA | Occupational Safety and Health Administration |
| RFID | Radio Frequency Identification (RFID) |
| GPS | Global Position System |

# Chapter 1

# INTRODUCTION

## 1.1 Background

Previous studies and statistics indicate that working on construction projects is constantly dangerous around the world (Kasirossafar et al., 2012). The role of safety in construction industry is very essential in order to reduce fatalities and injuries in the construction site. Safety management is a main issue in construction industry, and should be considered in project planning and design to make the workplace safe condition and also promote workers' safety.

Traditional safety planning still largely relies on paper-based 2D drawings and schedules to understand the needs for safety tools on a construction jobsite (Chantawit et al., 2005). Also, safety plan suffers from a separation between design and implementation phases in construction process. Traditional methods depend on safety inspections to recognize potential safety hazards points and collect them from construction 2D drawings, which are implicated and difficult to detect the potential hazards locations in various construction stages based on static drawings on the paper.

However, these hazards are subject to modification based on different situations such as bad weather and delays in material delivery, that could lead to change in a safety plan. In traditional method to update the safety plan every time schedule changes.
At these times, development of new tools is prompting designers to consider stakeholder's safety in their project. Thus, the awareness of necessity for safety planning is increasing in the design process. Also, designers must ensure that construction workers are aware of their duties that address in the design of the project. Also, a powerful safety planning has a vital role in decreasing overhead cost and delays (Bansal, 2011).

For proper safety planning, however, identification of safety hazards plays a significant role during all stages of a project, which should be subsequently considered at the initial stages of a construction-site procedure. Also, it is essential to identify all potential site hazards at each stage of the project on construction site and eliminate or avoid them before accidents happen. To identify site hazards, technology has played a vital role in the construction project. It is believed that the availability of technology makes the construction safety reachable (Zhang et al., 2013). Development of innovation technologies increased safety performance in the workplace but most of them were limited to reflect the site safety management process in the construction stage.

During construction phase, health and safety monitoring has a great impact on construction site hazards. The objective of monitoring and control system is to make sure that health and safety implemention is based on safety rules and standards during the project. Traditional monitoring depending on visual inspection and paper based checklists to control hazards situation/locations was difficult to provide immediate feedback. However, in recent years, using innovation technologies assist safety manager to promote safety control with real time feedback to prevent fatalities and injuries.

## 1.2 Research Objectives

The scope of this research is to increase health and safety in construction industry and decrease construction accidents during the project. This study aim to assist managers to ensure that construction health & safety performance whether are applied during the project or not.

Therefore, the manin objective of this research is:

1. To develop a framework for the pre-construction and construction phases to identify hazards situation and eliminate them before accidents happen.
2. To utilize BIM and innovation technologies from design to implementation phases in more accurate and fast ways compared to traditional methods.

## 1.3 Research Methodology

The applications of Building Information Modeling (BIM) in construction design and planning are increasing rapidly. 3D/4D BIM model have brought many advantages to construction health and safety and logistics applications as well. However, only limited automation in modeling and design processes has been exploited until now. This study, therefore, aims to improve safety in the pre-construction and construction phases by using BIM and innovation technologies to identify potential site hazards and eliminate them to achieve the goals in construction project. This research has developed the framework to find a new method by using innovation technologies for construction safety during the project. Figure 1 briefly describes fivestages of the construction projects safety framework in this research.

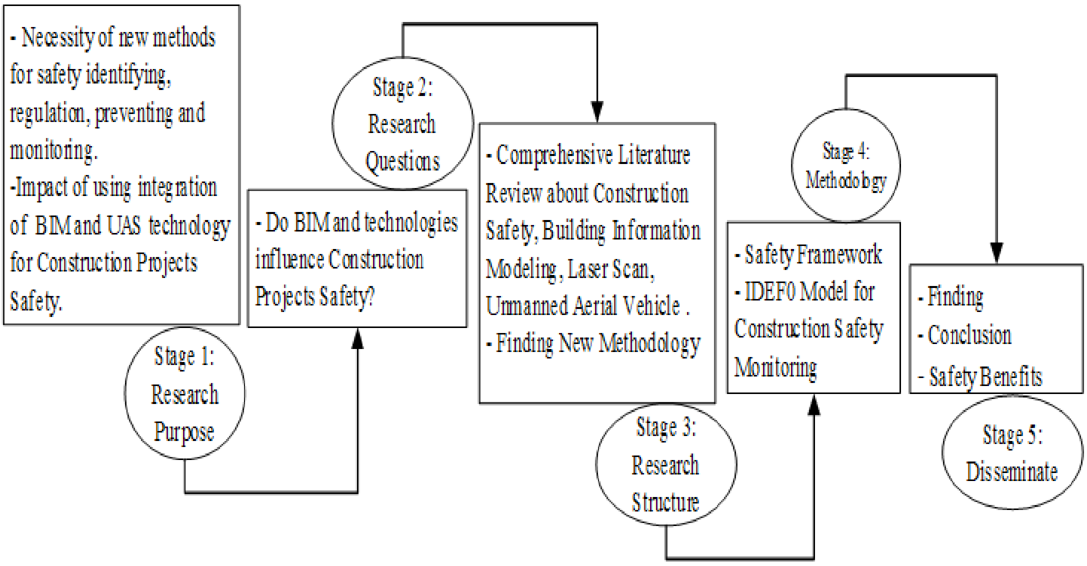


Figure 1: Research Framework

In spite of the role and power of governments' authorities in reducing fatalities and injuries in construction process, the lack of rules for monitoring and controlling health and safety regulations can be felt. To cope with this government issue, the proposed methodology has the ability to satisfy the benchmarks of health and safety active monitoring.

## 1.4 Thesis Structure

This thesis contains 5 chapters. Chapter 1 is includes the briefly introduction about the construction safety, the objectives and framework of this research. Chapter 2 presents a complete research that consists of a study for health and safety in the construction industry, Building Information Modeling, innovation technologies, Laser Scan and Unmanned Aerial System (UAS). Chapter 3 describes the methodologies of the study step by step. While, chapter 4 contains results and discussions about the safety framework evaluation. At the end, chapter 5 presents the summary of the study and conclusions from the benefits of this study. Finally recommendation for future studies are presented.

# Chapter 2

# LITERATURE REVIEW

## 2.1 Introduction

This chapter as shown in figure 2, consists of 4 stages. It includes a comprehensive literature review about construction safety, building information modeling (BIM) and innovation technologies. Also, present briefly Laser Scan and Unmanned Aerial System (UAS) as an effective technologies in construction safety. This chapter aims to indicate the benefits and potential of innovation tools and technology in order to achieve improvement in the construction safety management systems.

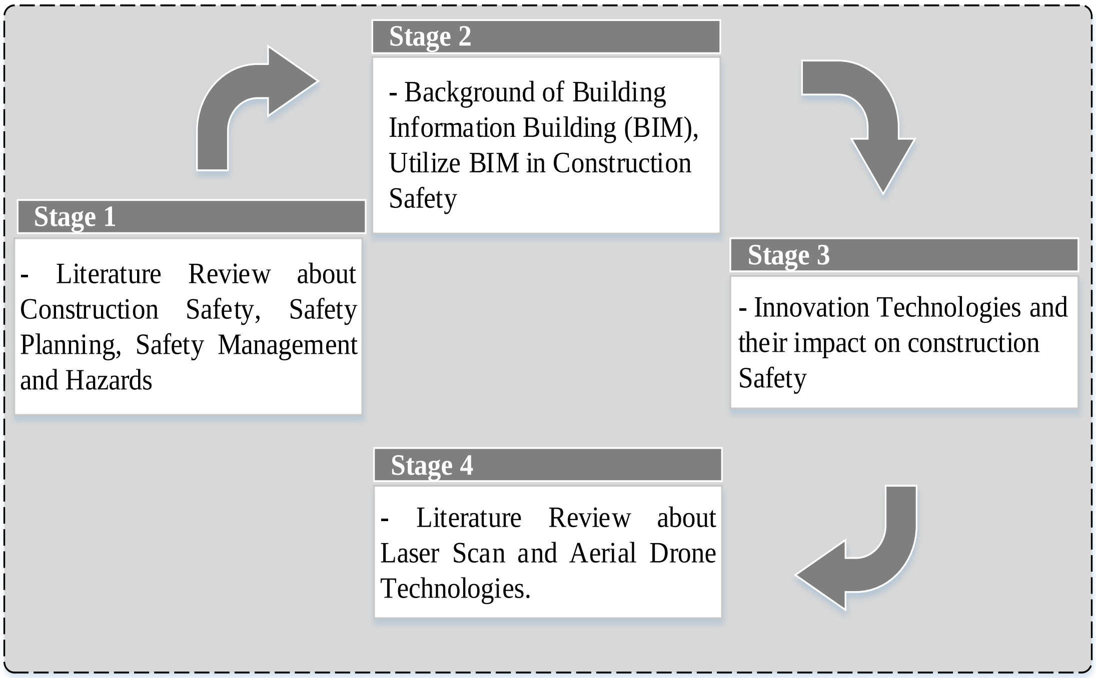


Figure 2: Overview of Literature Review

## 2.2 Health and Safety in Construction

Research studies and statistics indicate that construction industry is known as one of the greatest dangerous working around the world. Undoubtedly, construction jobsite has been remain on of the most unsafe workplace. In comparison with different industries in the US, for example, construction keeps on being positioned among the maximum records for work environment fatalities each year (Marks and Teizer, 2013). In 2014, 908 workers fatalities resulted in US construction and the rate of illness and injury was 3.6 per 100 full time construction workers in US industry (Bureau of Labor Statistics). Therefore, the risk of injury or fatalities at work in construction sector is considerably greater than in others industry. Statistics show that the percentage of accident happens in the jobsite increased recent years. Falling is the most common accident that happens in construction site (Zhang et al., 2012). Traditional fall protection plan relied on paper, for example figure 3 illustrates a traditional fall prevention plan where differents fall protection methods have been marked into the project 2D plan with different colors. The most frequent causes of accident fatalities and injuries are shown in figure 4:

**Fall hazardous locations on 2D plan**

Figure 3: Traditional fall prevention plan

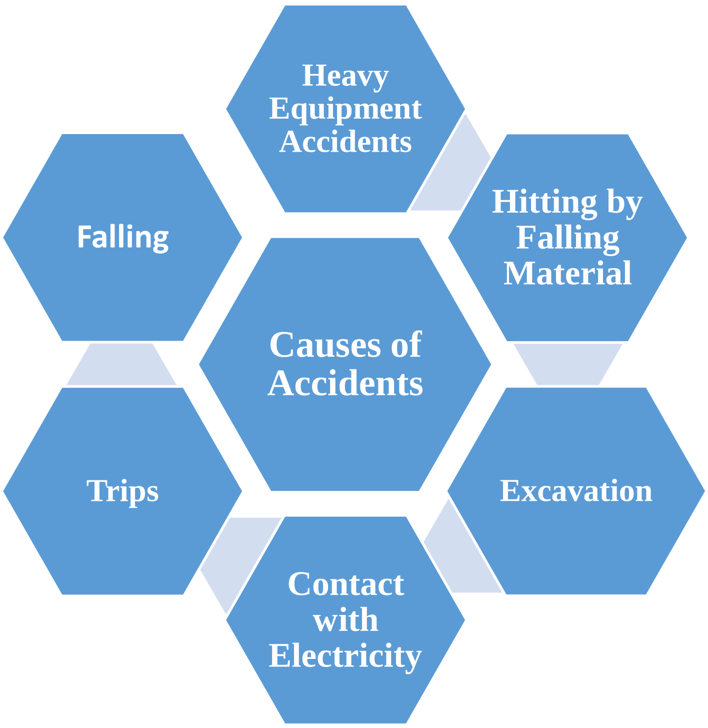


Figure 4: Frequent causes of accidents and fatalities

**Falling:** Falling is the most common type of incidents in the construction site.

**Trips:** It can be easily prevented by efficient management in corridors, stairwells, etc.

**Contact with Electricity:** Workers injure by electric shock and burns when they contact overhead power lines and buried cables or when they use unsafe equipment.

**Excavation**: It can lead to dangerous accidents involving workers at the jobsites. Construction workers can be critically injured or die in cave-ins

**Heavy equipment accidents:** A construction site is a hazard place that includes heavy equipment and materials that are in movement to each other and can lead to accident among them.

**Hitting by falling material:** The causes of accidents are famous and often repeated. Nearly all fatalities and accidents on work environment are usually avoidable through the operation of an efficient safety plan during the project.

### 2.2.1 Construction Safety Planning/Implementation

Safety planning is generally considered to be a primary necessity in safety rules and regulation. Although there were no standards for safety before 1970, the Occupational Safety and Health Administration (OSHA) has produced standards for safety and health in the construction site for the last four decades. It aims to protect workers through the hazards of work environment. The safety regulation and standards provided by OSHA have a great impact on promoting health and safety on the site. In spite of all these improvements, there is still a gap in construction safety. In many countries, the safety performance in construction sector is left behind other industries (Hon et al., 2011). As shown in figure 5, according to Bureau of Labor Statistics in US construction industry the number of fatalities increased between 2011 to 2014. Also, figure 6 indicate the number of fatalities in US construction of buildings. Clearly, the construction industry is actually far away from the vision of ‘‘zero accidents/injuries’’ espoused through several organizations related to construction (Zhou et al., 2015).

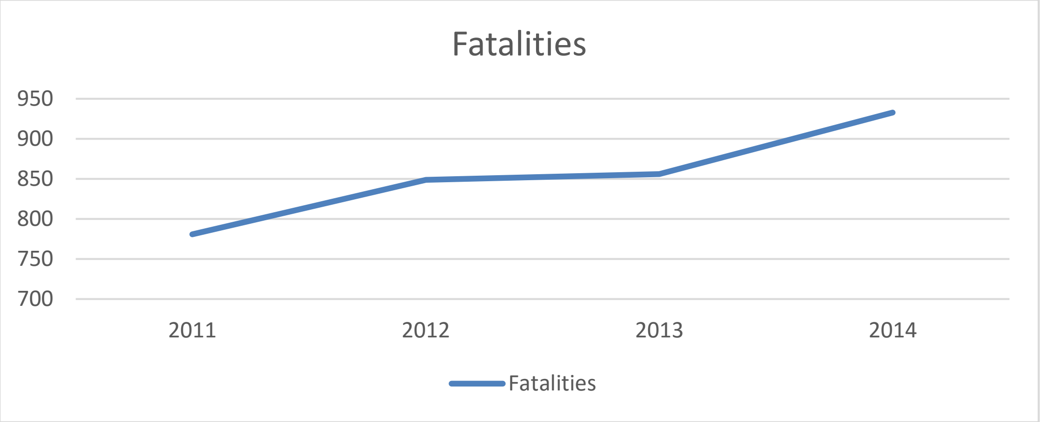


Figure 5: Number of fatalities in US construction industry
( Bureau of Labor Statistics)

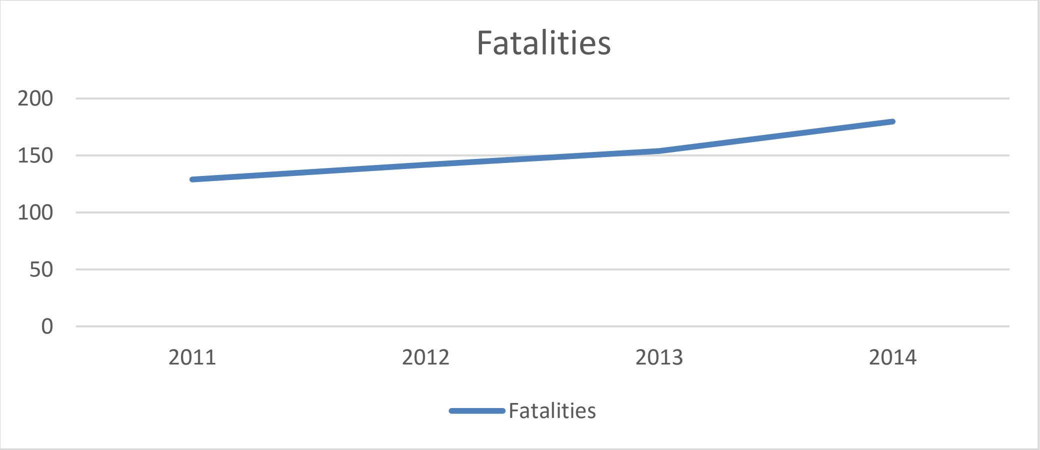


Figure 6: Number of fatalities in US construction of buildings
( Bureau of Labor Statistics)

To achieve ‘‘zero accidents/injuries’’ construction safety has an important role during the project. Developing site safety management system is the main issue for construction companies around the world. Numerous companies in the world are executing safety and health management system to prevent accident, remove hazards and to provide a safe jobsite in the projects. Studies have shown that owners, design team members, constructors, and construction managers have separately affected construction workers` safety (Rajendran and Gambatese, 2009). Most construction projects include the participation of these person. Therefore, they have significant role in construction safety process by taking responsibility when preparing construction safety plan. Safety planning is a significant part of safety management system. It aims to reduce construction site accidents. Poor safety planning often leads to fatalities and injuries. Traditionally safety planning is managed separately from project design and planning task (Chantawit et al., 2005 ). It can be used along with time, costs, schedules and other important tasks. It is very necessary to create a link between safety plan and construction schedule to aware when and where safety measures on the safety planning must be utilized. During safety planning, it is possible to recognize hazards situations and removed them before accidents happened. Providing a safe and healthy workplace as a teamwork is not an exception in this sector. Mitropoulos and Memarian (2012) indicated that team processes influence construction workers' safety. Moreover, the project team members can be aware of the safety requirements throughout their own duties when reviewing the planning of the project (Benjaoran and Bhokha, 2010).

### 2.2.2 Safety Management

While the issue of improving safety has been an industry need for years, it is very important to regard how safety management system are being executed in the construction project, as well as the advantages of a safety program. It is clear that safety program is a vital key to prevent construction site accidents and hazardous. An effective safety program can be reached if every workers and engineers promote their knowledge and skills on construction safety in the jobsite.

Safety management covers from planning to implementation (Chantawit et al., 2005). The expression safety management system refer to the management of occupational health and the environment as well as safety. It needs to be considered as the basis for safely site implementation to prevent construction accidents. Benjaoran and Bhokha (2010) on the practice of construction safety management in Thailand found that most construction projects did not systematically execute the safety management on the project site. Efficient safety management try to make the workplace safe and also promote workers' safety. Generally, safety management cannot happen without having an efficient safety planning. Health & Safety should be a key element in a safety planning for earning benefit in the construction safety from the beginning of the project. Traditional safety planning relies on observation, and being aware of all hazard points on construction site all the time for a safety manager was not possible (Zhang et al., 2012). Safety planning itself includes the recognition of all potential hazards and also determining the particular safety measures (Bansal, 2011). It is not acceptable to identify hazardous situations on construction site only after a related accident has previously occurred (Yang et al., 2012). Predicting potential hazards and probability of accidents is an important step in the design phase during safety planning. It is better to eliminate hazards at the design stage instead of looking on the construction phase. Gambatese et al. (2008) after analyzing previous studies exposed that there is a relationship among accidents and the design in the construction safety concept. Zhang et al. (2015) recognized and removed fall hazards in the planning phase of the project. The safety design could be the best solution with the aim of reducing the rate of accident and injury in construction. Designers can be able to decrease safety hazards in the project by considering construction workers` safety as a main factor in their design decisions (Huang and Hinze, 2006). They should consider workers into the design and implementation of safety plans. Also, designers must ensure that construction workers are aware of their duties that address in the design of the project.

## 2.3 Building Information Modeling (BIM)

### 2.3.1 BIM Definition

The term “BIM” often refers to the program that assists engineers to create a relationships between building components and represents them in 3D environment. Building Information Modeling (BIM) is a great visualization tool that represents a 3D of the virtual project. Visualizations tools give a better perspective of what the virtual model may appear and this can be achieved by using BIM, which was presented in the year 2000 as an advanced tool applied during design and planning phase. Basically, it is a new technique to simulate the project and change process of design in construction industry. In other words, it is the process of virtual design throughout construction procedure.

### 2.3.2 BIM in Construction

In the last decade, BIM has seen a dramatic development in use in the construction design. The ability of BIM allow for a better transition from design to construction. BIM as a new tool in construction industry has altered the techniques and process of design, planning, construct, manage and also supervise the operation and maintenance of buildings during the project. This can offer benefits to the construction industry in different parts based on a computer and software technology. BIM also be able to automatic and quick changes to the model by a project team member during design process.

3D BIM model makes integration between structural and mechanical system and design phase. By integrating 3D BIM model with time and schedule, the 4D model can be developed to connect each part with the related task and their relationships and sequences in planning phase. The 4D model shows 3D model of project components being constructed with the progression of time. 3D/4D BIM can guide designer to enhance quality and sustainability in the project. In addition, by integrating time and cost information, which is known as 5D model, problem of rework is decreased during the project. 5D BIM model can be utilized to manage the cost in the project, also it assist construction managers to fit the budget.

BIM can be utilized in all stages of the project life-cycle and indicate every detail in model to improve construction process. Therefore, engineers try to promote the application of BIM software science, which could lead to a significant change in construction industry.

### 2.3.3 BIM Software

Currently, in the market there are a wide variety of BIM software's platforms utilized by AEC Company, it has several types of software which are used to illustrate the result of the system such as Autodesk Revit, ArchiCAD, Navisworks manage, Tekla structure and Bentley. These softwares are also able to schedule the project from beginning and estimate cost.

One of the important software is Revit, It is used by designers and engineers, structural engineers, mechanical, electrical and plumbing (MEP) engineers, to design and simulate the model. Revit is a design and documentation system that delivers information that can aid engineers in project planning, scope, quantities, and design the structure of the project more accurate and easier.

### 2.3.4 BIM in Construction Safety

Recently, many accident prevention programs, tools and technologies have been developed in the construction industry. In the construction industry, there is a growing interest in the use of BIM to simulate, planning and construct building. However, the power of BIM is not limited to its ability to help only in design stage. Nowadays, many researchers are attempting to implement the use of BIM in order to promote various aspects of the construction procedure including the management of the construction site and the use of models on-site (Trani et al., 2015). Also, the importance and use of BIM-based model have increased within construction safety. The utilization of BIM can result in developing health and safety by joining the safety issues more closely to safety planning, preparing new methods for managing and controlling consecutively in the work environment. It was applied in construction safety as a main tool in design-for-safety or prevention through design (PtD) to help stakeholders. Visualization tools can make an opportunity to aid designers to recognize critical hazardous points and eliminate them during design phase (Kasirossafar and Shahbodaghlou, 2013). It can be helpful in safety management and promote safety performance of construction-site personnel by visualizing hazardous situations (Shen and Marks, 2015).

Safety planning and controlling are an important part of the project. Safety planning methods can be developed by using BIM-based plans ( Sulankivi et al., 2009). BIM-based 4D CAD was applied in construction site as a main tool to increase safety ( Zhou et al., 2012).

Kasirossafar et al. (2012) after investigating the effect of 3D/4D BIM model on construction safety and health indicated that 75 percent of respondents felt that in the construction industry accidents and fatalities can be preventable by utilizing 3D/4D BIM techniques in a design phase. The utilization of BIM and other visualization tools can result in developed occupational safety by allowing stakeholders to visually control construction work enviroment situations and identify dangerous work environment. In addition Qi et al. (2011) developed a safety design tool in construction that can automatically check fall hazards in 3D model and make an alternative design.

Therefore, health and safety in construction are promoted by utilizing BIM applications. Although, Ganah and John (2014) after analyzing the usage of BIM pointed out that respondents were to some extent skeptical about using BIM for health and safety, just 2.2% of respondents always utilized BIM.

## 2.4 Innovation Technologies

There are many factors that impact injuries and fatalities rates separate of the regulatory activities of OSHA. These include employer's practices in safety; worker training at the construction site; management of the jobsite; the influence of new technologies in the project.

Variety of approaches and technologies have been developed to achieve benefits in design-for-safety or safety performance. More and more researchers attempt to integrate innovative technologies with safety as an efficient solution to prevent construction accidents and enhance safety in the construction industry. In the recent years, many articles have been published with a variety of technologies in construction safety. Monitoring the construction site and worker/equipment safety has been executed with the use of Radio Frequency Identification (RFID) technologies, Ultra-wide Band (UWB) and Wireless Networks (WN) and BIM applications (Skibniewski, 2014). RFID can be linked into the BIM applications to indicate all elements that are in the correct locations. Also, Global Positioning Systems (GPS) and sensor technologies can enhance the safety performance of construction workers and equipment by preventing accidents that happen on construction site. 3D laser scan has a potential to record hazards location by creating 3-D point cloud model. And also. By taking images of construction sites, safety managers are able to control the construction progress through a real-life environment. Furthermore, Game technology developed the virtual training environment for students and workers.

Table 1 illustrates 40 articles and 15 types of technologies and approaches that are used in construction safety. As shown in table 1, many articles contain more than one technology or approach. It was discovered that, BIM and 3D/4D model have a boundless potential to integrate with technologies in construction health and safety.

Table 1: Technologies and Approaches in the construction safety

| Technology and approach | Reference(s) |
|---|---|
| **Augmented Reality (AR)** | Le et al. (2015) |
| **Global Position System (GPS)** | Pradhananga and Teizer (2012) |
| **Laser Scan** | Marks et al. (2013)- Wang et al. (2014)- Wang et al. (2015) |
| **Ultra-Wide band (UWB)** | Carbonari et al. (2011)- Hallowell et al. (2010)- Hwang (2012) |
| **Geographic Information System (GIS)** | Bansal (2011) |
| **3D** | Bansal (2011)- Chantawit et al. (2005)- Chu et al. (2013)- Dawood et al. (2014)- Guoa et al. (2012)- Jung et al. (2013)- Kasirossafar and Shahbodaghlou (2012)- Kasirossafar and Shahbodaghlou (2012)- Kasirossafar et al. (2012)- Lin et al. (2011)- Miller et al. (2012)- Qi et al. (2011)- Son et al. (2011)- Sulankivi et al. (2010)- Zhang et al. (2012)- Zhang et al. (2013)- Zhang et al. (2015). |
| **Virtual Reality (VR)** | Irizarry and Abraham (2005)- Le et al. (2015). |
| **Building Information Modeling (BIM)** | Chantawit et al. (2005)- Collins et al. (2014)- Ganah and John (2014)- Ganah and John (2014)- Kasirossafar and Shahbodaghlou (2012)- Kasirossafar and Shahbodaghlou (2012)- Kasirossafar et al. (2012)- Qi et al. (2011)- Riaz et al. (2014)- Riaz et al. (2015)- Sulankivi et al. (2010)- Wang et al. (2015)- Zhang and Bai (2015)- Zhang et al. (2012)-Zhang et al. (2013)- Zhang et al. (2015). |
| **Sensor** | Choe et al. (2014)- Lee et al. (2009)- Riaz et al. (2014)-Riaz et al. (2015)- Zhang and Bai (2015). |
| **Game Technology** | Dawood et al. (2014)- Guoa et al. (2012)- Liaw et al. (2012)- Le et al. (2015)- Lin et al. (2011)- Miller et al. (2012)- Son et al. (2011). |

| | |
|---|---|
| **4D** | Bansal (2011)- Chantawit et al. (2005)- Collins et al. (2014)- Dawood et al. (2014)- Kasirossafar and Shahbodaghlou (2012)- Kasirossafar and Shahbodaghlou (2012)- Kasirossafar et al. (2012)- Miller et al. (2012)- Sulankivi et al. (2010)- Zhang et al. (2013)- Zhang et al. (2015). |
| **Radio Frequency Identification (RFID)** | Chae and Yoshida (2010)- Hallowell et al. (2010)- Kelm et al. (2013)- Lee et al. (2012)- Marks and Teizer (2013)- Zhang and Bai (2015). |
| **Wireless Network (WN)** | Lee et al. (2012). |
| **Robotic** | Chu et al. (2013)- Jung et al. (2013). |
| **Aerial Drone** | Gheisari et al. (2014)- Irizarry et al. (2012) |

Traditionally, safety managers control the construction site by their working experiences and visual observation. However, in recent years variety of technologies have been developed to monitor performance of construction site and all technologies have the potential to promote site safety. Table 1 illustrates 27 articles and 9 types of technologies that are used to control safety in the workplace and integration with building information modeling. As shown in table 2, variety of studies have been performed to improve the performance of progress monitoring. However, just 7 articles integrated with BIM. By improving different tools and technologies, many researchers have recognized that innovation technologies could be an efficient solution to the problem of construction safety site.

Table 2: Safety Control Technologies

| Technologies / Tools | Integration with BIM | Reference(s) |
|---|---|---|
| **Unmanned Aerial System (UAS)** | No | Gheisari et al. (2014) |
| | No | Irizarry et al. (2012) |
| **Radio Frequency Identification (RFID)** | No | Andoh et al. (2012) |
| | No | Chae and Yoshida (2000) |
| | No | Chae and Yoshida (2010) |
| | No | Chen and Zhang (2015) |
| | No | Lee et al. (2012) |
| | No | Kelm et al. (2013) |
| | No | Marks and Teizer (2013) |
| | Yes | Sattineni (2010) |
| | Yes | Zhang et al. (2013) |
| **Sensor** | No | Andoh et al. (2012) |
| | No | Choe et al. (2014) |
| | No | Lee et al. (2009) |
| | No | Luo et al. (2015) |
| | Yes | Riaz et al. (2014) |
| | Yes | Riaz et al. (2015) |
| | No | Zhu et al. (2013) |
| **Wireless Network (WN)** | No | Lee et al. (2012) |
| | No | Zhu et al. (2013) |
| **Global Position System (GPS)** | No | Pradhananga and Teizer (2012) |
| | No | Andoh et al. (2012) |
| **Image** | Yes | Sharqi and Kaka (2014) |
| | Yes | Sharqi and Kaka (2012) |
| | No | Kim et al. (2014) |
| **Geographic Information System (GIS)** | No | Andoh et al. (2012) |
| **Laser Scan** | No | Marks et al. (2013) |
| | No | Wang et al. (2014) |
| | Yes | Wang et al. (2015) |
| **Ultra-Wide band (UWB)** | No | Carbonari et al. (2011) |
| | No | Hwang (2012) |
| | No | Teizer et al.  (2007) |

## 2.5 3D Laser Scan

### 2.5.1 What is Laser Scanner?

Laser scanners are used to capture the geometry of three-dimensional objects or environment. The collected data can be used in 3D digital model. Many various technologies exist to gather 3D data, however, each technology comes with its own limitations, advantages and costs. In spite of these methods of recording information, laser scanning has recently been utilized to assist capturing data as well (Giel and Issa, 2011). A 3D laser scan is a tool that analyzes a real-world model or virtual environment as well as a setting to capture data with its shape and appearance (Georgopoulos et al., 2010). Laser scan can be used efficiently to create an accurate 3D model. The application of 3D laser scanner has been popular in the survey industries in recently years. Recent development in this technology have improved facility management in the architecture, engineering, and construction (AEC) sectors and have exposed new perspective in digital technologies (Huber et al., 2010).

### 2.5.2 Point Clouds Data

Point clouds data are a set of data points in coordinate system. They are excellent for visualization aims. They are a representation in 3D of an object or environment. Usually, laser scanners are used to gather enormous point clouds data and generate a real-life environment by using software. By using Autodesk Revit software, point clouds connect laser scans directly into the BIM process. By visualizing point clouds directly within the BIM software, it is create an as-built model more efficiently and preciseness.

### 2.5.3 Laser Scan in Construction Safety

Traditional methods refer to the manual process of gathering geometric information on a building site. During construction process, laser scan can create an effective relationship between site and design team by scanning an as-built model of building and work environment and compare it with the design 3D model. Many various technologies exist to obtain data from a workplace; however, this advanced technology is capable of generating 3D environment in an accurate and fast way from various locations in working environment. This innovation technology also has a potential to record hazards location by creating 3-D point cloud model. Wang et al. (2014) presented the method that identifies cave-in safety risk by using laser scan in construction excavation. In order to integrate the three dimensional model with point clouds, the 3D model is converted into a format which is certainly suitable for the requirement of the software that deals with point clouds (Zhang and Arditi, 2013). The process of transforming point cloud data directly into BIM is known as "scan-to-BIM" ( Xiong et al., 2013). Laser scanning can be used in the work zone to help the BIM process. BIM and 3D laser scanner technologies have presented a new opportunity for recording, mapping and analyzing building data (Mahdjoubi et al., 2013). Undoubtedly, integrating BIM and laser scan could have an effect on construction safety.

3D laser scanners can be used to improve safety management system by gathering critical hazards points. Safety manager can use laser scan on construction site to compare 3D/4D BIM model with extract data information to detect deviations in construction monitoring phase (as shown in figure 7). Wang et al. (2015) used laser scan and BIM to identify fall and cave-in hazards in excavation phase. Laser scan is also able to present the 3D model and identify hazards in different applications. It has different type of software in the AEC sector to represent the virtual environment. Revit is known as one of the most popular software used in many companies. It links point cloud data that gathered by laser scanner directly into the BIM model.

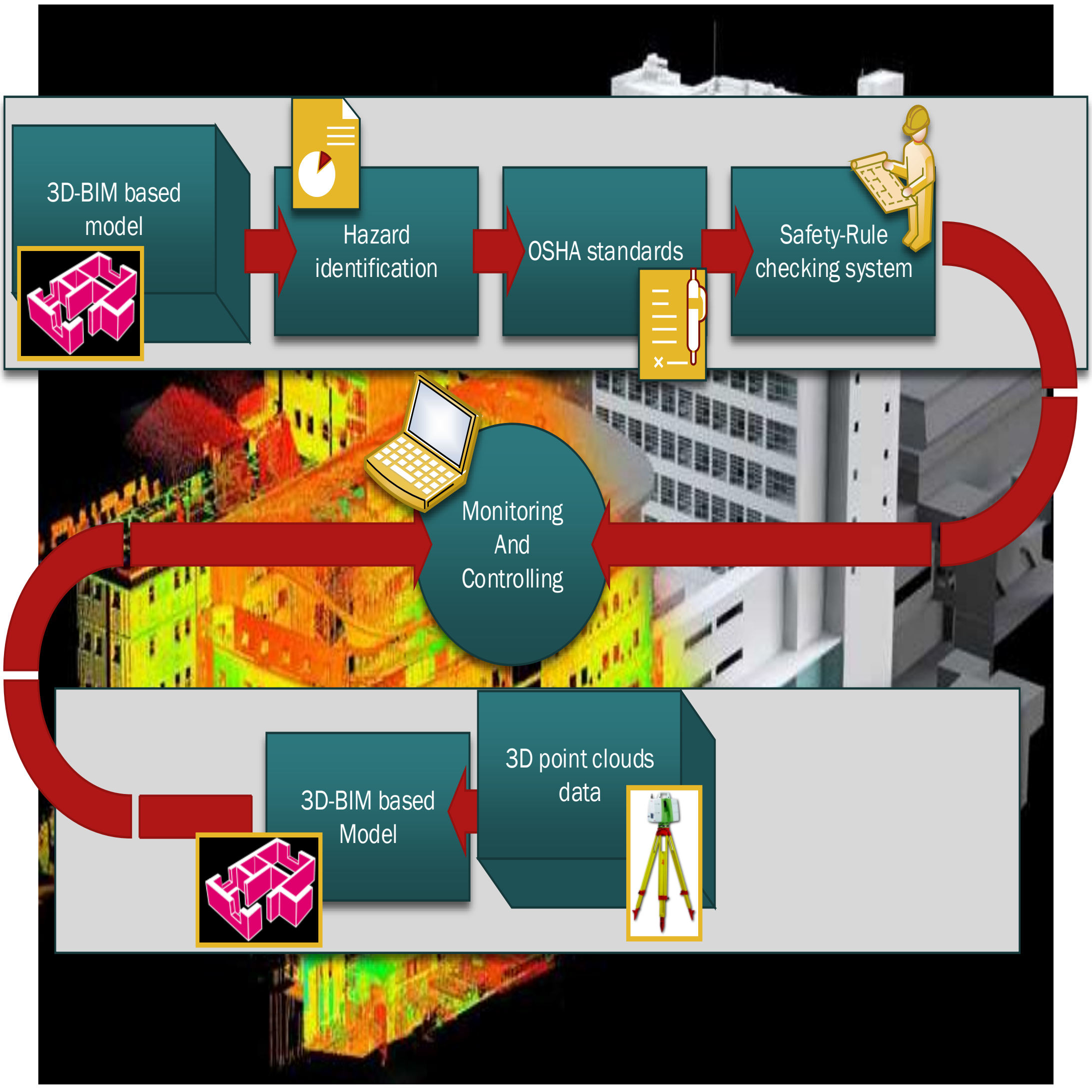


Figure 7: Integration of BIM and Laser Scan in construction monitoring

## 2.6 Unmanned Aerial System (UAS)

### 2.6.1 What is UAS?

Unmanned Aerial System (UAS) is an aircraft which are flying autonomously or be piloted remotely. In addition, UAS is described as a single air System, which normally includes three to six air Systems, a ground control place, and support equipment. It is also known as a Drone or Unmanned Aerial vehicle (UAV), Robot planes, pilotless aircraft, Remotely Piloted Vehicle (RPV), Unmanned Vehicle Systems (UVS) and Remotely Piloted Aircraft (RPA). While unmanned aircraft System (UAS) have been used for years, they are growing in number and effectiveness as aircraft, sensor and mature technologies. These days many of them control by iPhone or tablet and equipped with camera that can record and transmit photos or videos to the ground. They can gather high resolution imagery from various angles in an accurate and efficient way. These technologies have become cheaper and allow image capture at various distances and sensors including a Global Position System (GPS). A bout four years ago, the USA Army Armament Research and Development Engineering Center indicated a GPS-guided munition to utilize in mini UASs.

### 2.6.2 Usages of UASs

The uses of UASs technologies include range of issues that relate to collection, retention, use, exposure, and prevent destruction of necessary information. UASs technologies have been mostly used for military objectives for decades. The U.S. military used unmanned aircraft in World War I and World War II, it could be controlled by radio signals, usually from another aircraft. It has a significant role in gathering data regarding the operation of both enemies and friends by collecting real-time images or videos.

However, these days, they have been applied to aid in search and rescue and also use as an innovation tools in civilian environments has earned significant attention in domains such as mining industry, agriculture, forestry, archaeology, transportation and building. (Irizarry and Costa, 2016; Lee and Choi, 2016; Kim et al., 2016).

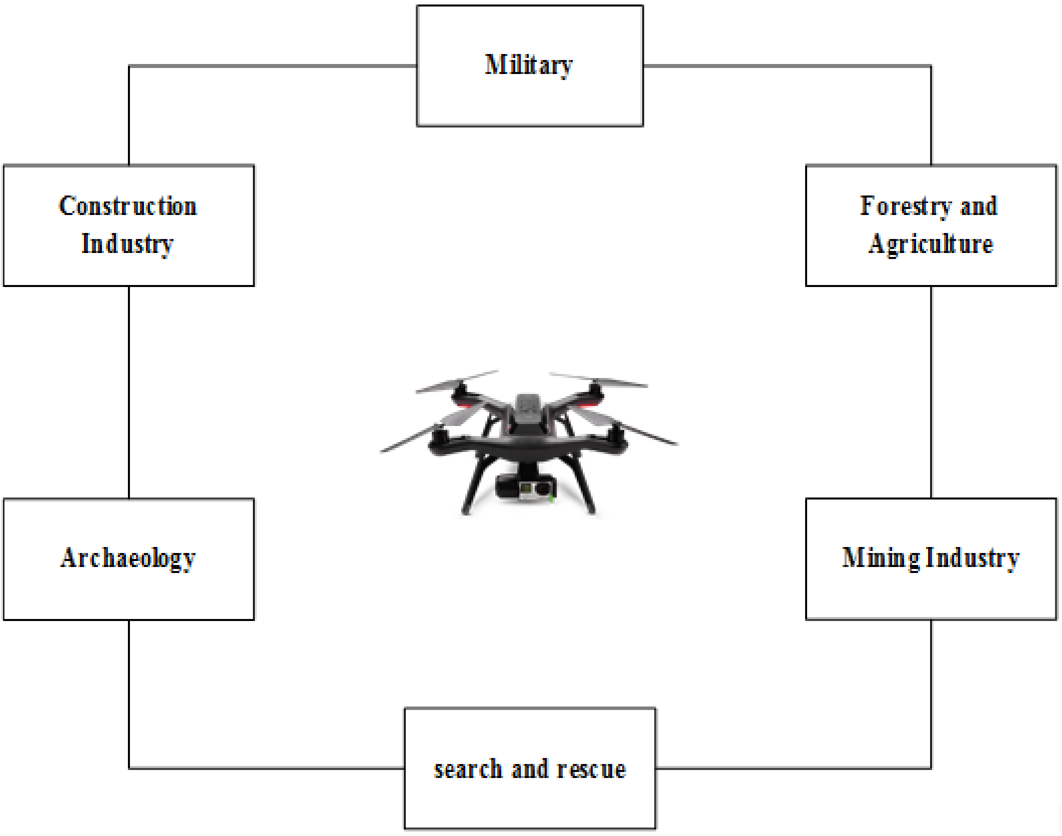

Figure 8: Usage of UAS

### 2.6.3 UAS in Construction

With development of real time monitoring technologies UASs provide many positive uses in civil engineering to control implementation of building, bridge and any infrastructure system. Also, they have been used in various transportation region, consist of monitoring and controlling traffic on roadways throughout and after emergency accidents or sever weather conditions, traffic data collection, traffic simulation, road surface distress, repair and maintenance of streets activities and managing work zone and traffic congestion to enhance the safety of workers. UASs, compared to traditional methods to control traffic, can fly over the work zone and ability to cover a larger area. Some researches have considered UASs for monitoring of bridges through their maintenance process.

Figure 9: Usages of UAS in construction

Table 3 indicates some applications and advantages of UAS technology that civil engineering utilize in construction process. As shown in the table, since only two studies use UASs as a safety checking tools in the construction industry. Therefore, it seems that in integration of UAS with safety more effort should be done to improve construction safety monitoring.

Table 3: Applications and Advantages of UAS technology in construction

| Applications | References | Advantages |
|---|---|---|
| **Project Progress monitoring** | Lin, Han and Fukuchi, et al. (2015)- Han, Lin and Golparvar-Fard (2015)- Lin, Han and Golparvar-Fard (2015)- Zollmann, Kalkofen and Hoppe (2012)- Zollmann, Hoppe et al. (2014)- Kluckner et al. (2011)- Rodriguez-Gonzalvez et al. (2014)- Freimuth and König (2015) | - Easy User Interface<br>- Autonomous Flight Capability<br>- Different Sensors equipped capability<br>- Flight Stability<br>- Communication range<br>- Real time response system<br>- Error Prevention<br>- Low Cost Operations<br>- Quick availability of New Data Capturing<br>- Can Fly Depending on Data Collection Needs<br>- High Quality-Resolution Data<br>- Lightweight and Easy to Transport<br>- Capturing easy to reach locations Views |
| **Damage Assessment** | Cornelius, Hänsch and Hellwich (2011)- (Eschmann et al. (2012)- Nathan et al. (2012)- Kerle, J and Gerke (2014)- Galarreta, Kerle and M (2015) | |
| **Surveying** | Fiorillo, et al. (2012)- Mcfarlane, et al. (2013)- Sebastian and Teizer (2014)- Boqin (2015) | |
| **Safety Checking** | Gheisari et al. (2014)- Irizarry et al. (2012) | |
| **Building Measurement** | Feifei et al. (2012) | |
| **Assembly Structure** | Alejo et al. (2014) | |

### 2.6.4 UAS in Construction Safety

With development of real time monitoring technologies UASs provide many positive uses in civil engineering to control implementation of building, bridge and any infrastructure system. They have ability to use in construction jobs better and faster over a number of applications. They are useful tools in monitoring the progress of construction activities. A camera-equipped UAS can be suitable for monitoring progress. In the large construction projects they are very helpful in monitoring the project from site preparation through to project completion. UASs technologies can easily monitor all part of the project site by flying around the construction site under a safety manager's control and transmit real-time high resolution photographs and videos for inspecting safety purpose in the project. They help safety managers to aware unsafe situation/location of the project that are exist in construction phase. Job hazards can be recognized immediately and safety managers can be informed to solve the problem. Only under such an situations safety managers would be able to provide immediate feedback and interact with the construction workers (Gheisari et al., 2014). Irizarry et al. (2012) used UAS technology that circulates all around the site areas and provide real time image and video about what is happening on the construction work environment. In fact, one of the main task for a safety manager is performing periodical inspections of the whole construction site to control site situations based on safety standards (Irizarry and Johnson, 2014).

### 2.7.4 Difference between Laser Scan and UAS Technologies

Laser scan and UAS technologies can be used as a capturing tools during monitoring the construction process. These technologies have the ability to identify and control hazards situations in construction sites. However, laser scan cannot identify all types of hazards and it can used to detect fall hazards locations. Since falling is the most accidents that happened on construction site, it is very important to regard fall hazards.

UAS technology can be utilized to recognize all types of hazards such as blind spots. Also, it has the ability to fly in different floors and blind spots to gather real time photos and videos. By using UAS tools construction site hazards can be detected and managers can eliminated them before happening. Additionally, this technology give opportunity to safety managers for providing immediate feedback. Nonetheless, this research have focused on these two technologies in order to achieve improvement in construction safety.

# Chapter 3

# METHODOLOGY

## 3.1 Introduction

In order to achieve research objectives, in this chapter, it was tried to show how innovation technologies can be utilized for safety design, management, monitoring and control construction projects. As mentioned before, safety in construction has suffered from a separation between design and implementation phases. This study attempts to create a powerful relationship between pre-construction and construction phases by using innovation technologies. It is necessary for safety managers to recognize hazards and prevent them as much as their responsibility allows them.

This research aims to develop the integration of BIM and innovation technologies in order to achieve development in the construction safety. It is hard for safety managers to be aware of all hazards on the project site at all times. Therefore, the purpose of this study is create a framework to help safety managers to gather information during the project and also control the project under construction. At first, Laser Scan is selected to identify fall hazards then Unmanned Aerial System will be utilized to identify all construction site hazards.

## 3.2 Monitoring Construction Site by Laser Scan Technology

Laser scan can be utilized to identify fall hazards. Monitoring in construction promotes the effectiveness of any attempt and provides helpful information for safety managers during the safety process. As shown in figure 10, the data is transformed into BIM after points clouds data are gathered by laser scan technology. Right after monitoring project performance, the critical hazards points in the construction site are collected and compared with safety-rules in 3D-BIM model. The data obtained by laser scanner could be scanned into a software such as Revit application to present the model. Laser scan helps safety managers to identify the difference between the design and the actual model and provides solutions to mitigate identified hazards in construction process.

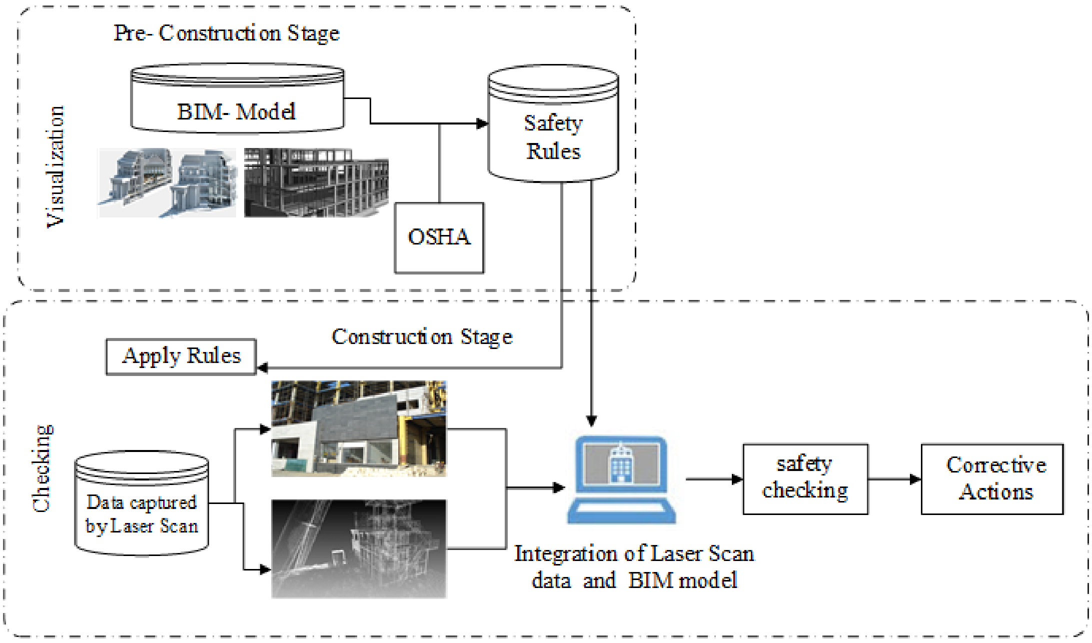


Figure 10: Safety Framework for Laser Scan

This part focus on fall hazards such as wall opening, edge on floors and hole in floor, roof, wall or any surface. According to OSHA definition, a “hole” means a gap or void of two inches (5.1 cm) or more in its least dimension (Zhang et al., 2012).

After extracting safety rules for protection fall hazards in design phase, control by laser scan starts in construction phase. As shown in figure 11 Laser Scan can gather 3D point clouds data from various location. After transmit data to BIM software, 3D model can help safety managers to compare safety rules with 3D model and identify hazards situation and prevent them.

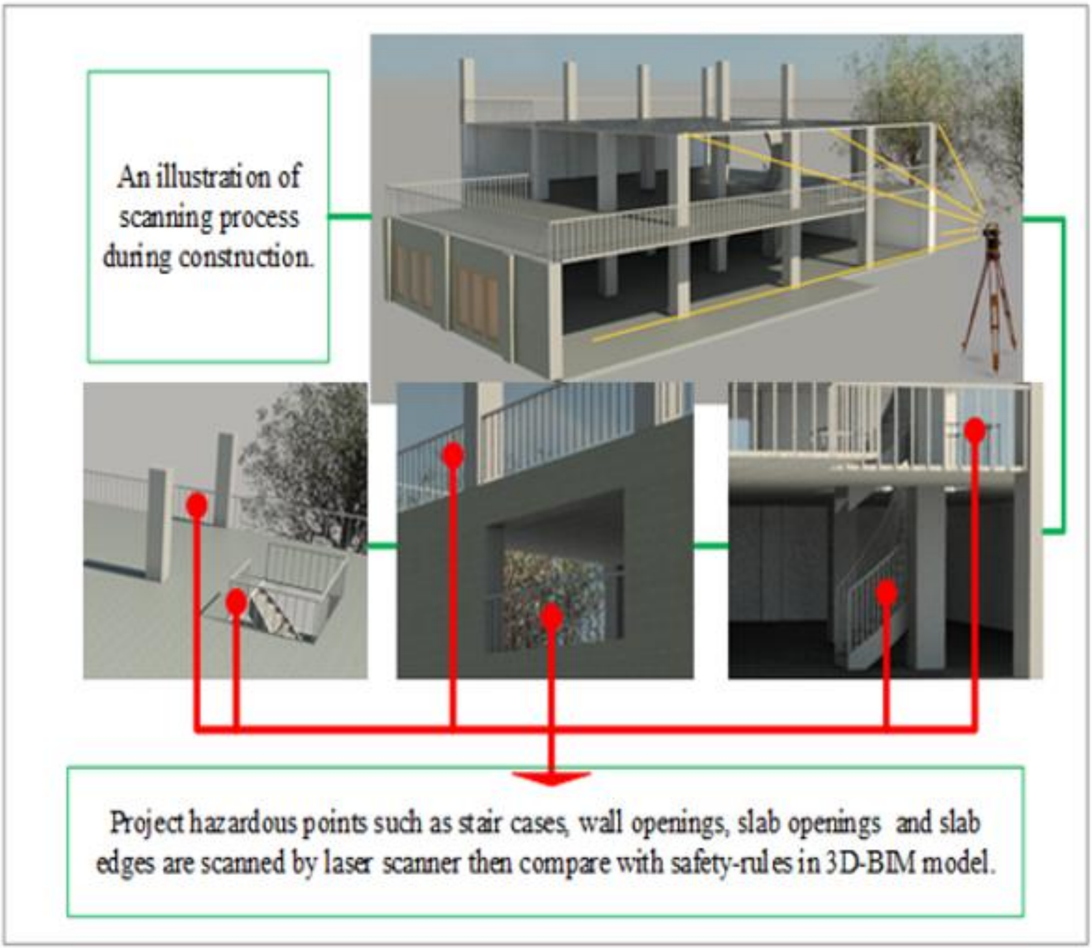

Figure 11: Fall hazard identification during construction

### 3.3 Safety Framework for Unmanned Aerial Technology

Until now, all capturing data technologies in construction safety aren't able to gather information from various locations and situations to detect hazards. In order to improve site safety we need an innovation technology to collect real time images or videos from all part of construction site. In recent years, Unmanned Aerial System (UAS) as a real time capturing data technology use in construction site to promote safety. This technology has ability to capture data from different locations and cover all type of hazards. In this research UAS is selected to control construction site during the project.

The main objective of study is to create a framework to help safety managers to enhance safety during the project and also to organize and control the project under construction. The proposed framework for a novel safety management and visualization system (SMVS) system is demonstrated in 2 parts.

Figure 12 demonstrates the framework for construction safety in 2 parts: pre-construction and construction phases. In the first part, 3D BIM-base model can be used along with safety rules and regulations to identify critical hazards points and their locations. 3D model is very applicable to prepare a safety-rule checking system that can be used in construction stage. In the second part, safety managers can utilized the UAS technology to control construction site. This technology is very helpful to follow the construction safety-rule checking during the construction process. UAS has ability to control all parts of construction site and identify all types of hazards. Until now, all capturing data technologies in construction safety aren't able to gather information from various locations and situations to detect hazards. However, UASs have ability to fly around the site and circulate in different floors to detect hazards situations. In order to improve site safety we need an innovation technology to collect real time images or videos from all part of construction site. In recent years, Unmanned Aerial System (UAS) as a real time capturing data technology use in construction site to promote safety. This technology has ability to capture data from different locations and cover all type of hazards.

By following these regulations in the construction stage, each project can improve safety of all stakeholders. It is helpful to follow the construction safety rules during construction process. This system has a potential to assist designers, workers, safety managers to mitigate construction accidents and fatalities.

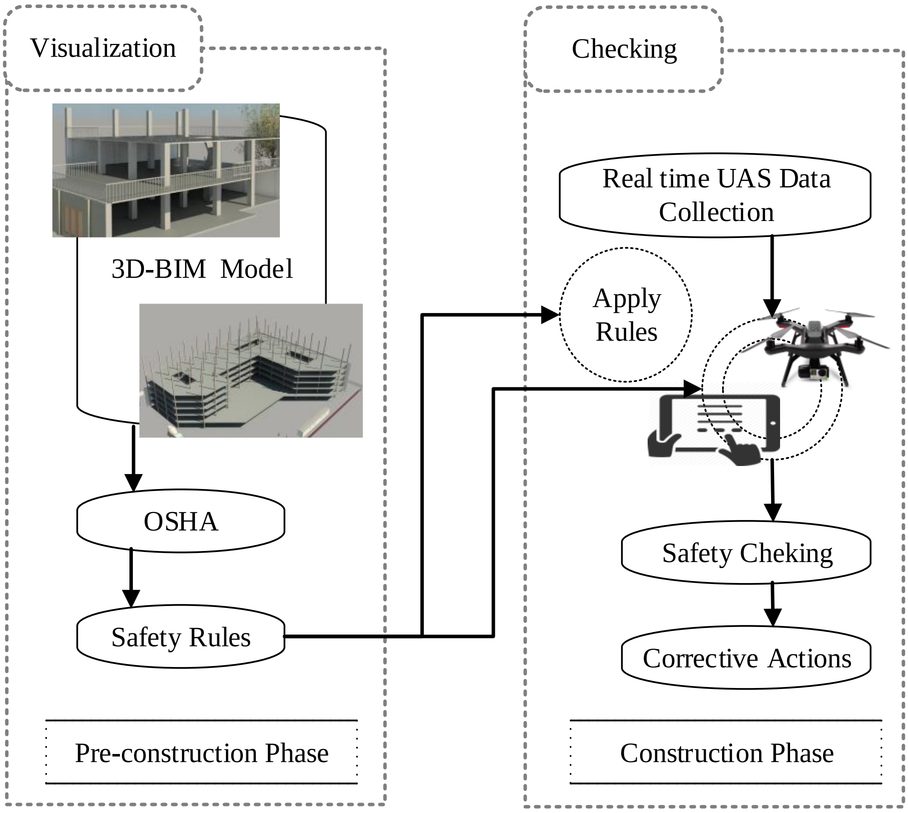

Figure 12: Safety Framework in pre-construction and construction phase

## 3.4 IDEF0 for Construction Building Project Progress Safety Monitoring

This model presents the development of safety framework for construction progress monitoring. The proposed framework is developed with detail of each process to enhance safety during the construction phase. The model is described schematically as an IDEF0 diagram. As shown in Figure 13 it consists of four sequential processes that include boxes and arrows. Each box indicate in detail the monitoring process. The model illustrate the relationship between pre-construction and construction phase. The activities of this model include the construction phases relating to the design of the building to control safety during implementation stage. All of these process in IDEF0 model are shown in table 4.

Table 4: IDEF0 Model Activities

| **Diagram Reference** | **Activities** |
|---|---|
| A0 | UAS-based Construction Project Safety Inspection |
| A01 | BIM-based Model |
| A02 | Safety Regulation |
| A03 | UAS-based Collection of Safety Inspection Dynamic Data<br>A031 Identify Best Location For Capturing<br>A032 Capturing Photo and Video From Identified Location<br>A033 Real-time Sending Data to Inspection Engineer |
| A04 | Analysis Project Safety |

As shown, first 2D, 3D and schedule are necessary to create a BIM-based model. This BIM model can be utilized with Occupational Health and Safety Regulation (OHSA) to create process monitoring. By preparing safety rules and regulation in pre-construction phase, hazards points monitor in construction phase. In this study, UAS technology as a capturing tool is proposed. During monitoring site, it is important to identify best location for gathering real time images or videos and then sending data to inspection engineer to analysis project safety with safety regulations.

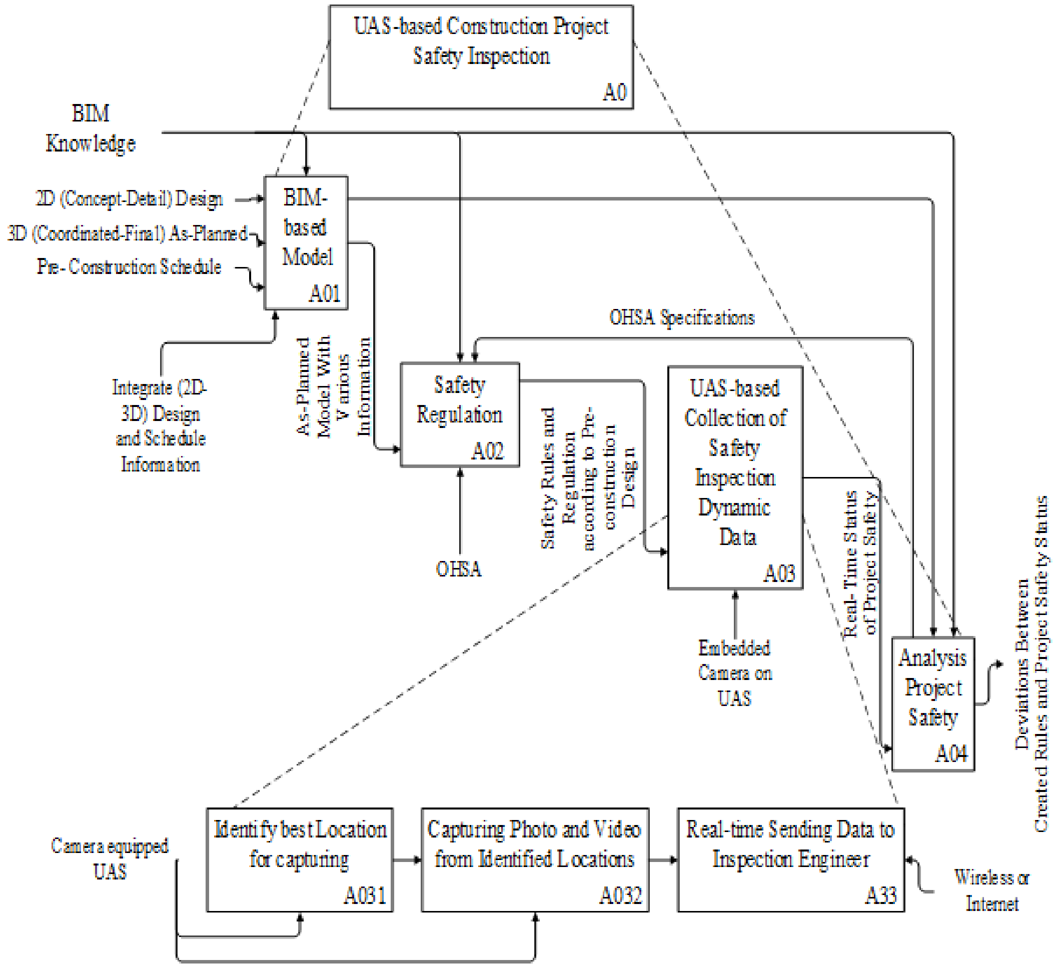


Figure 13: IDEF0 Diagram for Construction Project Progress Safety Monitoring

### 3.4.1 BIM-Based Model (A01)

By using 2D/3D design and schedule information and simulations, the project team members can communicate more efficiently and execute a safety planning. In this research, BIM-based model is used to detect hazards on the site. Identifying dangerous situation and their location in 3D model can be utilized to warn workers of the likely loopholes before construction phase.

At the present time, various BIM-based software are used by designers. One of which is Revit software. This software is chosen for designing construction model to integrate building information and visualize in tree-dimension model. BIM-based model is developed to find a prevention method to promote safety in construction. By having an efficient connection of 3D model with the planning and also execute health and safety in the project, the goal of giving a great potential to increase benefits to the construction industry can be achievable (Hayne et al., 2014).

### 3.4.2 Safety Regulation (A02)

This report focuses on hazard identification and prevention based on the model. Safety rules and regulations can be utilized in conjunction with a BIM-based model and plan information to detect safety hazards in the safety-rule checking system (Zhang et al., 2013; Zhang et al., 2015). In this stage, relevant construction safety standards are extracted from OSHA and linked with the 3D BIM model to identify hazardous situations and eliminate them in pre-construction phase. It is helpful to reduce the possibility of hazards before they occur. Safety-rule checking reports will be utilized to assist safety managers to inspect that safety execution follows rules and regulations during the construction phase.

### 3.4.3 UAS-based Collection of Safety Inspection Dynamic Data (A03)

Construction industry utilizes monitoring and system controls to prevent various changes that occur on site. Monitoring performance of construction promotes the effectiveness of any attempt and provides helpful information for safety managers during the safety process. In this model the progresses of the construction are monitored and controlled.

Recent years, many technologies have been advanced to aid in the control and monitoring of the performance of jobsite. In this research, as shown in figure 14, during the monitoring process, safety manager use UAS technology to detect hazards situation and their locations in the work environment. This new technology can fly over the construction site and collect real time data from the location of construction personnel and equipment, hazards materials, moving equipment and also blind spots to eliminate unsafe conditions before accidents happen.

### 3.4.4 Analysis Project Safety (A04)

Analysis Safety in construction projects play a significant role to prevent accidents that occur on construction site, but is often a difficult task due to the constantly changing work environment. Hazard identification is the necessary part of construction site as safety performance in the construction industry is extremely complex. This process considers any activity that may cause accident in construction. It can use to prioritize safety tasks and give an attention to the most critical ones. Hazardous workplace does not just affect site safety, it has also a huge impact on time and cost (Yi and Langford, 2006).

By using UAS technology in this model critical hazards point identify and prevention method consider immediately to avoid accidents. The manager be able to walk around the site and control safety issue more efficient with a device to solve the problem immediately. Although, it is more effective to avoid hazards at the design stage instead of looking for hazards in the controlling stage.

Finally, this model helps safety managers to ensure that the main hazards that may cause harm were identified and prevention methods were taken into account during each stage of the project.

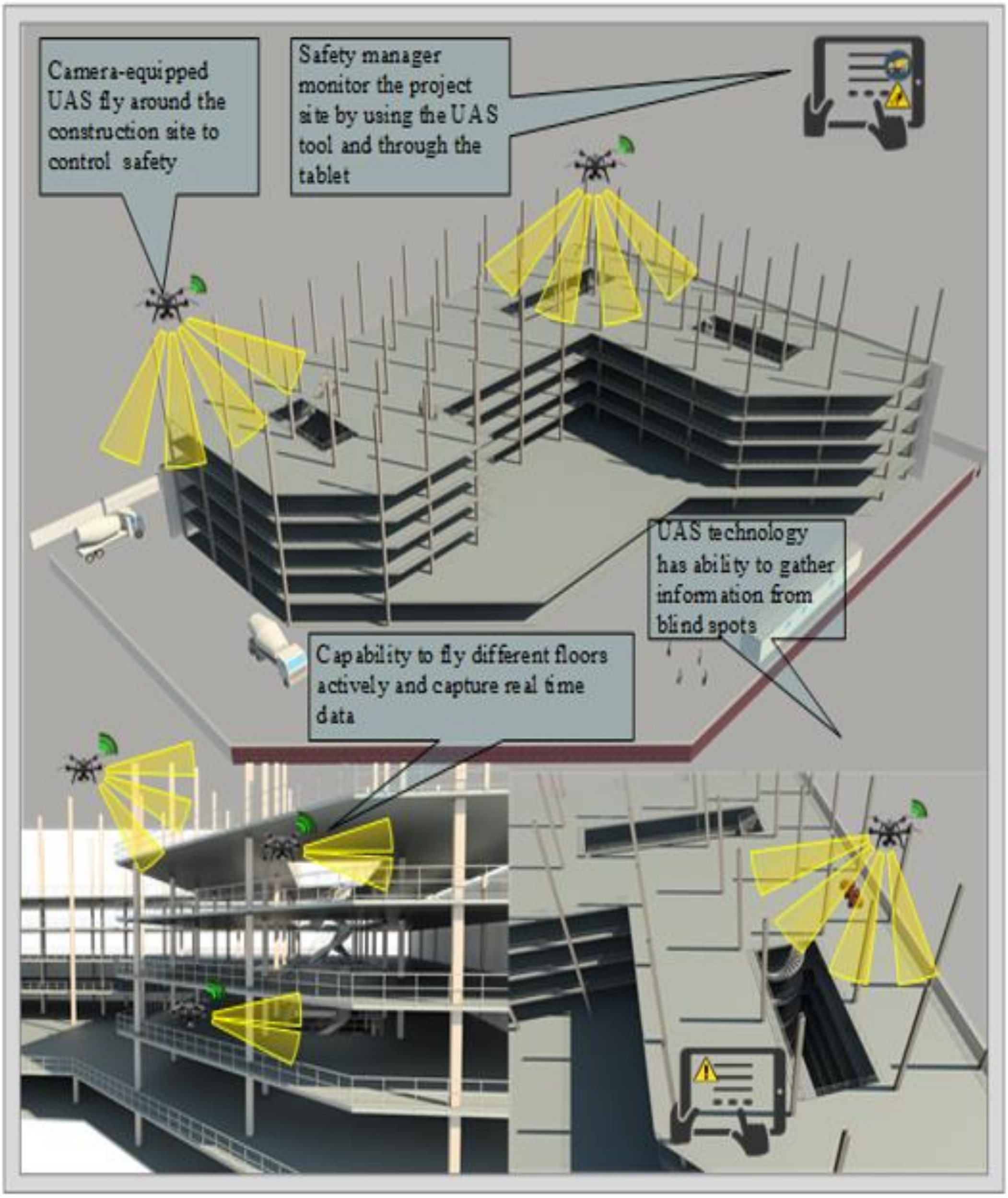

Figure 14: 3D Simulation of Monitoring and control in construction phase

## 3.5 Evaluation of Framework

The objective of evaluation of the safety inspection framework is to study the effectiveness of a practical action and validation of it. Also, the safety framework has been evaluated to get recommendations from various construction professionals for further advance in the safety framework to use in a real project. In this evaluation, the research considers many construction safety factors during construction.

The evaluation survey was administered to various stakeholders involved in 83 designers, civil engineers, safety managers, project managers, contractors and other professionals working in construction industry in three countries such as Iran, Turkey and Dubai. More than 75% of the respondents have more than 10 years of experience working in construction and rest of the responders have less than 10 years. And also, 74% of the respondents believe that falling is the most frequent construction accidents in their projects.

The quantitative analysis results collected from evaluation responses to UAS-based safety inspection framework are shown in table 5. The questionnaires were asked to rate different aspects of the framework concept. It was based on a Likert scale and ranged on five point, which represented from poor to excellent to gain quantifiable feedback.

Table 5: Evaluation Responses to UAS-based Safety Inspection Framework

| Number | Evaluation Questions | Rating (%) | | | | | |
|---|---|---|---|---|---|---|---|
| | | 1: Poor | 2: Fair | 3: Satisfactory | 4: Good | 5: Excellent | Mean rate |
| 1 | To what extent can Safety Model improve hazards identification? | - | - | 10 | 28.4 | 61.6 | 4.85 |
| 2 | To what extent can Safety Model improve elimination of hazards? | - | - | 9.2 | 31 | 59.8 | 4.81 |
| 3 | To what extent can Safety Model improve control jobsite hazards | - | - | 11 | 26 | 63 | 4.92 |
| 4 | To what extent can Safety Model improve identification of all types of hazards? | - | - | 14.6 | 39.4 | 46 | 4.27 |
| 5 | To what extent can Safety Model improve reduction of accidents? | - | - | 5 | 41 | 54 | 4.52 |
| 6 | To what extent can Safety Model improve the protection of workers? | - | - | 9 | 30.8 | 60.2 | 4.70 |
| 7 | To what extent can Safety Model improve the early detection and correction? | - | - | 20 | 25 | 50 | 4.43 |
| 8 | To what extent can Safety Model improve Relationship between Pre-construction and Construction Phases? | - | - | 5.7 | 41 | 53.3 | 4.51 |
| 9 | To what extent can Safety Model improve real time feedback? | - | - | 21 | 30 | 49 | 4.31 |
| 10 | To what extent can Safety Model improve the reflection of construction site situation | - | - | 3 | 39 | 58 | 4.76 |
| 11 | To what extent can Safety Model improve the rapid/comprehensive emergency project assessment? | - | - | 24.8 | 40 | 35.2 | 4.35 |
| 12 | To what extent can Safety Model improve the site logistics visualization? | - | 3 | 23 | 30.7 | 43.3 | 4.29 |
| 13 | To what extent can Safety Model improve the advantages gathered from the field information capturing technologies? | - | - | 11 | 65 | 24 | 4.3 |
| 14 | To what extent can Safety Framework improve the environmental situation information collection? | - | 8 | 12 | 43 | 37 | 4.32 |
| 15 | To what extent can Safety Model improve the quality control? | - | - | 9 | 37 | 54 | 4.53 |
| 16 | To what extent can Safety Model improve the static/dynamic safety analysis? | - | - | 30 | 41 | 29 | 4.15 |
| 17 | How easy is it to follow the Safety Model? | - | - | 8 | 41 | 51 | 4.48 |
| 18 | How useful do you consider the overall framework? | - | - | 10.7 | 29.3 | 60 | 4.83 |

# Chapter 4

# RESULTS AND DISCUSSIONS

## 4.1 Introduction

The model presented in this research provides a viable solution to prevent accidents in the construction industry. It uses the IDEF0 model to explain the inputs, controls, mechanisms and outputs of each process in the construction building project progress safety monitoring can easily adopt the model in real projects. The Safety Framework presented in this research was developed by using the IDEF0 model approach. Hence, the safety framework was represented in a process using IDEF0 technique is useful to demonstrate process in detail. The IDEF0 model was used to visualize and present the framework. It is easy to understand and has been proven appropriate to be used in construction industry. This chapter presents the discussion of evaluation framework from design to implementation. First, discussed the effectiveness of Safety Framework in construction industry instead of using traditional methods. And then the quantitative results of the questionnaire are discussed.

## 4.2 Framework Evaluation

The objective of evaluation safety inspection framework is to study the effectiveness of a practical action and validation of it. Also, the safety framework evaluate to get a recommendations from various construction professionals for further advance of the framework to use in a real project. Using a quantitative research method during the framework, evaluation helped the researcher in many ways. In this evaluation, the research considers many construction safety factor from design to implementation.

The Safety Framework guides construction companies to promote safety management system in the construction site. The Framework provides a methodology to integrate BIM and UAS in the project from design to implementation. The design of the evaluation research considered all factors that affect safety in a project. These are the significant factors that construction companies need to increase safety during their works. And it is very important to avoid any research bias during data collection.

This questionnaire allowed the collection of quantitative data. The questionnaire consisted of two parts:

Part 1: Background information that includes information about job title/position in the construction sector, country of their workplace, experience in the construction industry in terms of years, company name and address, and e-mail or contact number.

Part 2: Safety Framework section consist of questions about the effectiveness of the model and benefits according to the implemention of the framework in the project to increase safety in construction.

## 4.3 Framework Evaluation Discussion

Generally, regarding the reviewed literature and survey analysis on probable solutions to the health and safety issue, some items have drawn experts' attention a lot. These potential answers to the site health and safety matter are respectively:

- Hazard identification
- Elimination of hazards
- Controlling job site hazards

Concerning this study's aims, which are reducing job site accidents and creation of the proper relationship between pre-construction and construction phases, it is believed that the mentioned actions have the potential to resolve this research objectives. Nonetheless, other variables of the survey are also strongly recommended to be implemented and integrated with these actions in order to protect workers safety and reduce construction site accidents, optimistically to reach zero-accident or a hundred percent safe construction job site. The detail discussion is presented in the following.

The results indicate that the mean rate for all questions were higher than 4 in the evaluation. And hopefully all respondents answered completely the questions. The results indicate that the mean rate for 9 questions were higher than 4.5 out of 18 questions.

Control jobsite hazards and identify hazards situations and eliminate them are important issues in this research. Fortunately, the mean rate for these questions are higher than 4.8. Control jobsite hazards as one of the significant factor in this study has the highest mean rate in the evaluation framework. It means that this framework can cover control construction site hazards as well. However, they believe that the safety framework cannot cover all types of hazards because the mean rate for this questions is 4.27. Early detection is a significant factor that can help safety managers to prevent accidents before accrued, as the rate for this question is 4.43.

This study aims to increase construction workers` safety in the project and reduce construction accidents. Most of the evaluators inclined that this framework can increase protection of workers during construction. And considering this issue in the model is stronger than reduction of construction accidents. As shown in table 5 in previous chapter, the mean rate for protection of construction workers is 4.7 and for reduction of construction site accidents is 4.52 respectively.

The same as hazards identification and eliminate hazards, create a relationship between pre-construction and construction phases is also one of the main issue that considered in this survey to improve it by gathering innovation tools in the model.  By improving relationship between design and and implementation phases, managers can be able to increase safety and manage the project as well. Fortunately, the main rate for this issues is 4.51.

This research aims to improve reflection of construction site and provide immediately feedback by using UAS during control phase. As shown in the table the main rate for reflection of construction site is higher than the real time feedback.

Question 11 to 14 got a mean rate around 4.3. These questions are about improve project assessment, site visualization, benefits obtained from the field data capturing technologies and environmental condition data collection.

Regarding quality control is another issue that is considered in the evaluation of the framework. By improving this item, construction companies eager to use innovation tools and technologies instead of traditional methods.

In comparison with other questions in the evaluation survey statics/dynamics safety analysis got a lowest mean rate in the framework. The mean rate that has been gathered from evaluators is 4.15

It is very important to create a model that all companies can utilize it easily. If they think that following this model is hard for them, they never ignore traditional methods. This study attempt to create an easy safety framework that all construction companies can use it. Fortunately, responders inclined that this framework is easy to use it as the mean rate is indicated 4.48 in the table.

The main point in the evaluation framework is that the usefulness of the framework was rated as 4.83 in the survey. It means that different professionals working in construction industry are inclined to use safety framework. It is expected that, the safety model would become more popular among these professionals in the future.

# Chapter 5

# CONCLUSION AND RECOMMENDATIONS

## 5.1 Conclusion

This chapter presents the conclusions obtained from the previous chapters by emphasizing significant factors that were reached in this study. At the end recommendations for future studies are proposed. In recent years, construction projects environments are getting more and more complex and it can be hard to manage and control them with traditional techniques and methods. The management of construction hazardous is an important key to improve safety and this research tries to detect them with innovation tools.

This research presented a new methodology in construction safety to detect hazardous situations in order to prevent them in the project. It is useful to detect potential safety hazards and create communication between designers and safety manages to prevent hazards. This paper attempts to improve safety performance of construction-site workers to work more accurate and safer in both the design and construction phases compared with traditional methods. This research tries to create a powerful relationship between design and construction phases.

Firstly, the developed framework can prevent fall hazards locations by integrating BIM and laser scan tools to obtain and analyze data in construction sites. Secondly to identify all type of hazards situations, this study presented a new methodology based on the

BIM and UAS technology which will enable safety managers to recognize hazards in all project stages and develope suitable mitigation strategies. The developed framework indicates the capabilities of practical action in construction jobsites.

## 5.2 Design Phase

### 5.2.1 BIM-based Model

BIM is a powerful tool to use in construction design. Also this study has proven that BIM is an efficient tool in gathering, visualizing and monitoring data between various stakeholders in construction industry. BIM and visualization tools create opportunities for companies to have a successful management and implement a project in practical uses.

BIM offers many benefits that can improve construction safety. It has a potential to integrate design into the safety planning and decrease the possibility of accidents and reduction of project costs. BIM help designers in early identification of hazards to different design alternative. Although BIM tools have proved to be very helpful in the of design a construction project, we believe that BIM is not a useful tool only in the pre-construction of the project but can be included in the construction stage as well. Thus, it can be integrated with all stages of the project from design and planning during construction to increase health and safety in the construction sector. Also it can solve problems that are faced in various stages of construction projects.

To sum up, using BIM in construction provide many benefits during the project such as reducing time, cost and rework providing accurate plan to manage the site and improve health and safety. However, to apply BIM in the project suitable software must be bought and installed and companies should learn how to use BIM software. It has a potential to create competitive environment between companies in construction sector.

### 5.2.2 Safety Rules System

Occupational Safety and Health standards have a vital rule to identify hazards and prepare safety-rule checking system. Regarding safety rules and regulation during construction process help designers to design construction more safety and also assist safety managers to follow the safety in construction monitoring. This research emphasize that the role of OSHA is very significant for regarding construction workers employee. OHSA has made the workplace compliant to the regulation in the jobsite.

## 5.3 Construction Safety Monitoring

In the construction phase, it is hard for safety managers to control and identify all hazards in the site. To improve the current situation there are many factors that influence dangerous situations in a project; therefore, using innovation technologies as control tools could be helpful to enhance the safety of workplace through the construction.

However, many studies have focused on design for safety and much more used technologies through construction. More attempt, is needed to create a link between pre-construction and construction phases.

### 5.3.1 UASs Technologies

UASs technologies are innovation tools used in construction safety. And only a few study focused on these technologies to increase construction safety site. They have the ability to monitor all area in jobsite by flying around construction work environment. In means that it has a great potential to promote safety and assist safety managers to control site in large construction projects.

This research suggests safety managers could increase construction site workers safety by using technologies during the construction process.

## 5.4 Future Studies

Finally, future studies might need to focus on using more technologies in the life cycle of construction projects and how to integrate them from early stage of planning to other stages of construction, management, control and maintenance. Also, they need to prepare safety-rule checking reports at each stage of construction process.

There are two important types of barrier to improve safety in construction: knowledge and best process to identify them. Construction Safety Education is an important factor in construction health and safety. Safety knowledge is a basic step in construction safety. The objectives of safety knowledge is to enhance understanding of necessary safety information about the construction site. The construction industry has other tools that can help to promote safety knowledge. Using innovation technologies like 3D video game technology in academic areas like universities and colleges as training tools can help students to increase their knowledge about safety issues in a virtual construction site and enhance students learning in construction safety. They can also use in construction site to learn workers before they start to work. Game technologies provide a situation for construction workers about what will occur on construction site and develop their skills before they enter a real construction work environment.

To conclude, this study focuses on BIM-based technology in identification of safety hazards situation/location, prevention them and monitoring and control hazards points from pre-construction to construction phases in the project. To improve this research study, identifation of further works and development is needed to test the potential of the safety framework in practical action and see the result of the safety model in the construction environment. By using innovation methods and avoiding traditional methods, the rate of fatalities, injuries and accidents will decrease in construction sector so that the vision of ‘‘zero accidents/injuries’’ can be reached in construction industry around the world.

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# APPENDIX

## Appendix A: Questionnaire

1. What is your background or field of specialization in the construction industry?

-Safety manager

-Project manager

-Civil engineers

-Designers

-Contractor

-Other

2. How many years of experience have you had working and/or teaching in construction?

-1-5

-6-10

-11-15

->15

3. Where is your workplace?

-Dubai

-Iran

-Turkey

4. What are the most frequent construction accidents in your projects?

-Falling

-Contact with electricity

-Excavation

-Slip and Trip

-Heavy equipment accidents

Others…

5. How much substructure did you work in your recent projects? (Last 5 years)

-<1000

-1000-5000

-5000-10000

->10000

6. To what extent can Safety Model improve hazards identification?

7. To what extent can Safety Model improve elimination of hazards?

8. To what extent can Safety Model improve control jobsite hazards?

9. To what extent can Safety Model improve identification of all types of hazards?

10. To what extent can Safety Model improve reduction of accidents?

11. To what extent can Safety Model improve the protection of workers?

12. To what extent can Safety Model improve the early detection and correction?

13. To what extent can Safety Model improve Relationship between Pre-construction and Construction Phases?

14. To what extent can Safety Model improve real time feedback?

15. To what extent can Safety Model improve the reflection of construction site situation?

16. To what extent can Safety Model improve the rapid/comprehensive emergency project assessment?

17. To what extent can Safety Model improve the site logistics visualization?

18. To what extent can Safety Model improve the static/dynamic safety analysis?

19. To what extent can Safety Framework improve the environmental situation information collection?

20. To what extent can Safety Model improve the quality control?

21. To what extent can Safety Model improve the advantages gathered from the field information capturing technologies?

22. How easy is it to follow the Safety Model?

23. How useful do you consider the overall framework?