Improved Tower Cranes Operation Using Integrated 3D BIM Model and GPS Technology

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ABSTRACT

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Concordia University, 2014

Tower and mobile cranes are the most commonly used equipment on building construction jobsites. They play an essential role in material handling, placement, assembly and erection operations. Statistics reveal that during the last decade, the construction industry has suffered globally from crane related accidents. Hence, detailed study of different aspects of crane-based activity is important in terms of time and safety. There are several studies for enhancing safety conditions of crane operations on jobsites to decrease the number of fatalities and even increase the productivity. Existing approaches and studies have deployed wireless networks and tracking sensors to detect and identify workers, but high initial cost for installation and maintenance of these technologies and inappropriate feedback for disregarding workers privacy hold down their usability. The purpose of this study is to develop a proactive lifting operation management system to prevent potential accidents caused by tower cranes' components through using GPS in integrated 3D BIM models. In this study, generated workspaces are utilized to demonstrate areas occupied by workers or equipment instead of using individual tags for each entity. As construction workers may leave their work zone for some reasons, 3D video tracking is applied for identifying and tracking if workers leave their pre-defined workspaces. The developed model captures the load position in real

time and subsequently compares the load's bounding box position with defined area in BIM model. In the developed model, tower crane's load dimensions and starting point of the loading procedure are inserted and subsequently the model updates the load's position in real time. The updated position in the 3D model is checked proactively with existing spaces to send alerts in case of overlapping. Two case studies are used to demonstrate the concept and to validate the feasibility of the proposed method. In the first case study the added plug-in is used to generate workspaces for material, equipment and labors and in the second one, the real time safety system is validated in two different scenarios. The developed plug-in in Revit environment enhances timely proximity detection for enhanced safety since it detects objects based on pre-defined spaces and retrieves crane's load location in the model in real time. Identifying resources of interest which being free of tag and developing the real time conflict detection in Revit can be addressed as main findings of this study.

To: My beloved mother, my Inspiring father

Arezoo, Milad

Ava, Arsha

For their endless love.

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First and foremost, thanks God for what I have now and for which I have reached in my life.

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List of Abbreviations

Abbreviation	Description
API	Application Programming Interface
AEC	architecture/engineering/construction
BIM	Building Information Model
CAD	Computer-Aided Design
CSA	Critical Space Analysis
FLD	Fisher's linear discriminant
GIS	Geographic Information Systems
GPS	Global Positioning System
GUID	Globally Unique Identifier
HOG	Histogram of Oriented Gradients
NBIMS	National Building Information Model Standard
OSHA	Occupational Safety and Health Administration
PBS	product breakdown structure
PCM	principle component analysis
PECASO	patterns execution and critical analysis of site space organization
RFID	Radio Frequency Identification
RSS	Received Signal Strength
RTLS	Real time Location System
SIFT	Scale-Invariant Feature Transform
SURF	Speeded up Robust Features
SVM	support vector machine
UWB	Ultra Wideband
VR	Virtual Reality
WBS	Work Breakdown Structure
WCB	Workers' Compensation Board-Alberta
WGS	World Geodetic System

Chapter 1: Introduction

1.1 General

This research studies existing technologies and practices which have been applied in the construction industry for the purpose of improving safety and productivity of tower crane related activities. This research focuses only on safety and presents a new safety model for such activities by integration of the least number of tracking sensors and 4D BIM (building information model). The rest of this chapter includes the research background, motivation and objectives, followed by research methodology and the dissertation organization.

1.2 Background and Motivation

Highly dynamic environments are very inviting for accidents, and construction sites are not an exception to this rule. Continuously moving resources such as equipment, labors and materials on construction sites considerably increase likelihood of collisions among these resources. Heavy equipment such as tower cranes, excavators and trucks are involved in major accidents resulting in fatalities. In addition, blind lifting in crane operations may be considered as one of the most unsafe activities which could result in contact collisions with power lines, workers, obstructions and temporary facilities (Shapira and Lyachin 2009). Conducted studies by Peurifoy et al. (2006) and Shapira et al. (2008) highlighted the importance of blind spots in high rise and short buildings. Two significant reasons which are entailed in these incidents could be either related to lack of enough time for recognizing risky areas (Fullerton et al. 2009) or misinterpretation of involvers in crane operation. Therefore inserting the automated system is expected to lessen human error in daily activities. In recent years, following the evolution in the software engineering industry, the application of information technology in construction industry has been studied by several researchers in order to enhance safety issues and productivity on job sites. Many researchers have utilized image-based and range-based technology to alleviate risk of blind spot for crane operators (Li et al. 2013, Shapira et al. 2008, Teizer et al. 2010). But, the operator is still responsible for judging and evaluating the surrounding conditions and relative distances. On the other hand, an implemented investigation in 2007 showed that using real time information in construction sites can warn workers or operators when risk of contact collision exist (Teizer et al. 2010). With the aim of enhancement in real time safety management, effectiveness of radio frequency technology was assessed on resource interactions during construction daily activities (Marks and Teizer 2012, Teizer et al. 2010). Although utilizing RF technologies improves safety management by achieving positive results, these studies were tested on few workers on construction sites. This lead to augmentation of the installation and maintenance costs of the wireless networks in real project scale. In addition, the arising challenge of workers privacy who do not prefer to be tracked by managers or superintendents on job sites is another limitation with these new tracking technologies. Accordingly, developing a system utilizing a least number of tracking devices could be more acceptable, and motivate conservative attitude of the decision maker to apply novel management tools into construction industry.

In recent decades, tracking technologies have been used for several purposes in construction industry. Since resources interactions leads to completion of projects, tracking of these dynamic entities (e.g. workforce, equipment and material) is essential for several project management areas such as, time, cost, quality and safety management, etc. The most familiar location identifications methods that have been applied in the construction industry are Radio Frequency Identification (RFID), Ultra Wide Band (UWB) and global positioning system (GPS). These technologies are mostly used for equipment tracking, material delivery and checking the installation status (Park 2012). RFID has been used for tracking material and acquiring necessary information throughout a supply chain, while UWB is useable technology for indoor tracking of construction entities and also safety purposes. In addition to other technologies, GPS units are used widely in heavy construction machines for better control and increase of the job efficiency. However, equipping each entity with single tag or sensor for a project with hundreds of moveable resources can increase the project costs, which is most of the contractors' concerns (Park 2012).

Nowadays surveillance cameras become more popular in construction industry and the potential for monitoring construction daily activities cannot be neglected (Bohn and Teizer 2009). The camera network can be one of the contractors' preferences on construction sites. Economical price and good resolution of surveillance cameras are justifiable enough for contractors to be convinced. Real time recording and capturing system enable the superintendent to have an easy access into several views of job sites at the same moment. Several researchers have utilized vision-based technology for identifying project progress status (Son and Kim 2010, Golparvar-Fard et al. 2010). Since video-based technology can detect and track objects of interest based on their motion patterns and colors in two dimensions, video tracking system can be comparable with radio technologies if it provides depth information as well (Park 2012). This capability makes tracking process more applicable in dynamic media and also be more acceptable for personnel who feel uncomfortable with attached sensors.

Most existing research and studies in crane's safety issues, have tried to use real time tracking technologies such as UWB, RFID and GPS to improve safety conditions. Increasing number of the required tags or tracking sensors for individual entities to be tracked and following complaints from workers who feel being controlled, persuades me to propose a safety system which uses the minimum number of sensors and also considers existing obstacles in construction sites while tower crane is in operation. Such system can bring valuable improvements to both safety and efficiency of tower crane related activities.

1.3 Objectives and Methodology

The main objective of this research is to develop an automated tower crane safety model in BIM model by using GPS technology to improve safety conditions for the project entities. In this study pre-defined workspaces are used to identify and localize the project entities while the cost is considerably less than the current researches which use tracking tags. The main idea behind this study is to develop a safety detection system which acquires cranes' load position from GPS, recognizes occupied area from 4D BIM model, and compares them in real time. Meanwhile, workspaces are considered as static areas in this study and 3D video tracking system is adopted from Park's (2011) research to utilize in this model for tracking workers who leave workspaces.

In order to develop proximity safety system on construction sites, the tower crane operation is chosen in this research due to the following reasons (Sacks et al. 2005):

1- Tower cranes are capable of lifting different types of construction materials
2- Tower cranes are the most popular hoisting equipment on construction project

There are many potential interactions during tower cranes daily activities, as this type of equipment enables hooking and unhooking loads at various heights and radii. Consequently, tower cranes' components, such as hook and attached load, could be in proximity of different entities (e.g., other tower cranes, power lines, constructed buildings and labors). Therefore, this thesis places emphasis on proximity safety monitoring of tower cranes operation without consideration of weather impact.

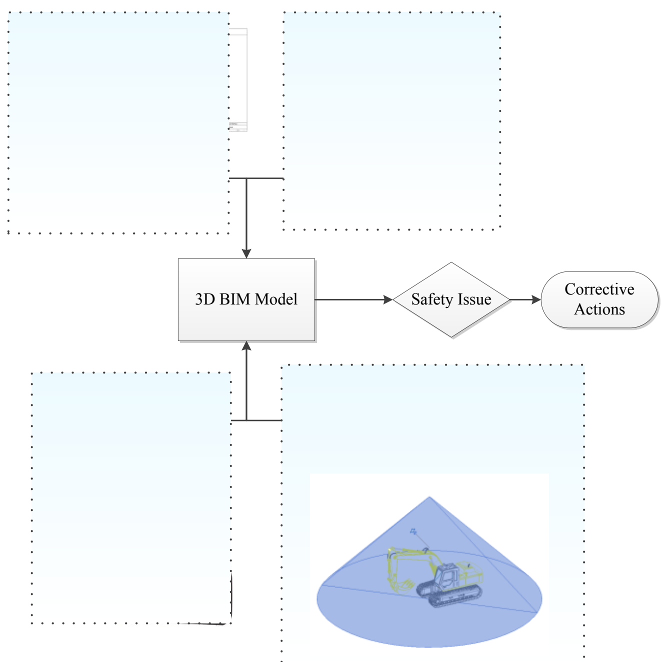


Figure 1-1: Schematic flowchart for proposed model

As it is illustrated in Figure 1-11, 3D BIM model will be used as the main environment for implementing the safety algorithm. The proposed methodology will be implemented within the BIM model. To begin, 3D BIM model is integrated by schedule as a fourth dimension to have current status of project. In the second step, workspace generator plug-in is used for allocating required workspaces. Next, the video stereo system supports the model with real time position of workers who are not in defined workspaces. At the end, the position of hook's load captured through the attached GPS unit and the existing information will be used in Revit model for identifying load's bounding box and safety checks.

1.4 Thesis Organization

Chapter 2 reviews the literature on crane related accidents and their frequency of occurrence. It continuous to outline recent and studies related to the most commonly used tracking technologies in construction projects. BIM concepts and workspace's application are briefly reviewed also in this chapter. The chapter ends with summary on limitations of current safety approaches as well as the potential use of workspaces.

Chapter 3 presents the proposed model, including the application of workspaces and BIM model in order to identify the status of construction entities involved in the operation being considered. This is then followed by proposed integration of GPS technology and BIM. The chapter ends with an overview of proposed model.

Chapter 4 includes description of model implementation. It covers in detail the developed plugins in BIM model. Also, the features and interfaces are shown in a step by step guide to explain how the developed system works. This chapter concludes by presenting few case studies which are used to validate the developed model.

Chapter 5 summarizes the presented study; highlighting the main contributions and limitations. It also suggests areas for future research.

Chapter 2: Literature Review

2.1 General

Construction industry includes several interacting resources which these interactions lead to project completion. Unfortunately, dynamic nature of construction industry has been found as a major contributor to the most unacceptable accidents. Individual carelessness or fatigue due to repetitive tasks causes fatal accidents on the job sites. Tower cranes as a significant lifting resource in construction activities, enable transporting of materials and components and provide the mobility of project entities. Regardless of tower crane's positive impacts on project progress, it could be associated with negative influences on project efficiency, companies' status and also general safety in case of happening accidents.

Regardless of existing published reports about crane accidents in construction industry, these statistics are not efficient enough to be applied for analysing death and injury cases and know the major causes of the accident. There are several institutes and organizations have published many guidelines and safety rules in order to make job sites safer and also lessen the rate of accidents. Although these guidelines and safety rules improve safety condition in construction activities, human actions are error-prone, especially when they are not well-focused.

The advent of computer technologies have helped construction industries in several aspects of management tools, but this evolution can be extended more in order to improve the site safety issues. There are many tracking technologies that have been integrated in construction projects or equipment with the goal of safety improvement.

BIM model and visualization tools have recently become more popular as well. Integration of tracking technologies and BIM model has attracted many researchers in recent years. In order to have background idea about previous studies, this chapter will cover background studies of the safety and its significances, the current methods and technologies utilized on construction projects for improving safety or productivity. It will also illustrate building information modelling (BIM) and workspace management impacts on construction industry.

2.2 Construction Industry Safety Statistics

The scattered and dynamic nature of construction project resources (materials, equipment and tools, personnel, and temporary facilities) increases the probability of collisions and accidents on construction projects. These daily interplays having the capacity to become more risky and dangerous due to existing of many distractor factors which decrease the individual awareness on construction sites (Teizer et al. 2010).

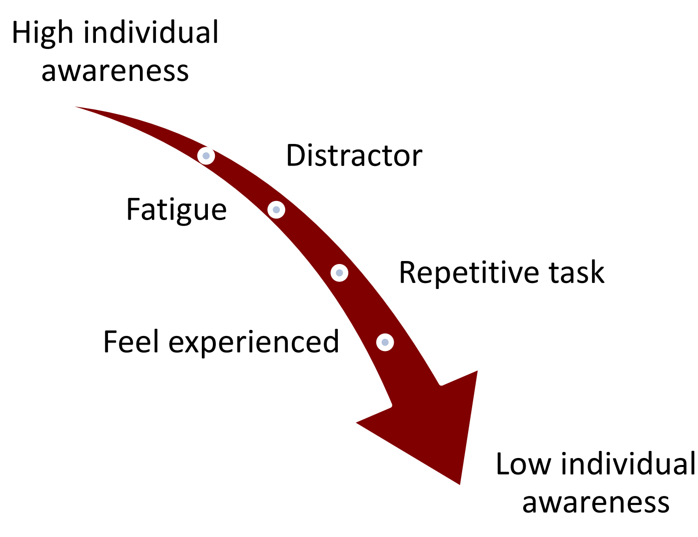


Figure 2-1: Individual awareness trend in daily activity

According to recent published statistics by Workers' Compensation Board-Alberta (WCB-2011), construction industry fatalities number amongst the major industry sector is considerably bigger than others with 453 fatalities from 2001 to 2010. As can be seen in the Table 2-1, workplace incident types are tabulated based on kind of events or exposures. In general, workplace incidents refer to situation, where the labor deceased due to injuries at a jobsite. It can be realized from the table, the three first main types of incidents are: contact with objects and equipment (30.9 %), falls (18.4%) and transportation accidents (11.3%). In addition, struck by object was the most frequent event in the contact with objects and equipment sub-category (WCB-2011).

Table 2-1: Workers' Compensation Board-Alberta Fatalities Report (2011)

Type of Event or Exposure	2001-2005	2006-2010	Number of Fatalities	%
Contact with Objects and Equipment	59	67	126	30.9
Struck by Objects	38	36	74	18.1
Caught in Objects	20	29	49	12.0
Struck Against Objects	1	2	3	0.7
Falls	34	41	75	18.4
Fall to Lower Level	24	25	49	12.0
Fall on Same Level	9	13	22	5.4
Other Falls	1	3	4	1.0
Transportation Accidents	16	30	46	11.3
Exposure to Harmful Substances	13	23	36	8.8
Fires and Explosions	9	6	15	3.7
Assaults and Violent Acts	10	5	15	3.7
Assaults/Violent Acts by Persons	8	5	13	3.2
Other Assaults/Violent Acts	2	0	2	0.5
Overexertion	1	7	8	2.0
Bodily Reaction or Exertion	1	8	9	2.2
Other Bodily Reaction/Exertion	0	6	6	1.5
Unknown	45	27	72	17.6
Total	188	220	408	100.0

The following chart also reveals the practical safety guidelines' influence on the trend of fatality rate. Although it has a fluctuating behavior, but the moderate slope on trend line from 2001 to 2010 confirms this reduction (Workers' Compensation Board-Alberta 2011).

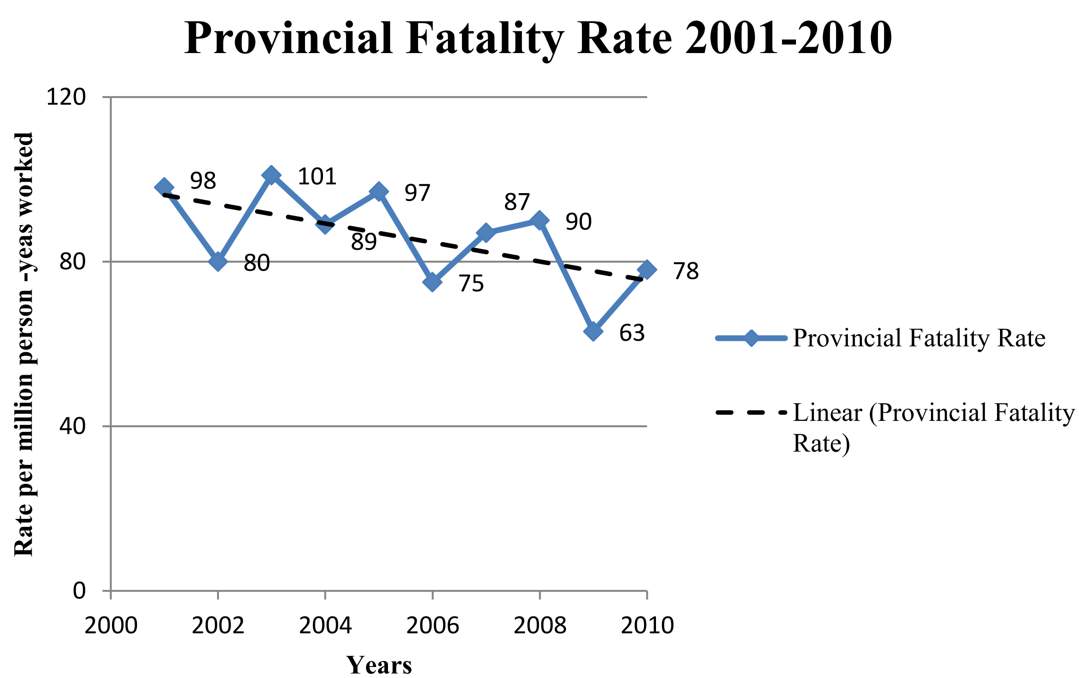


Figure 2-2: Provincial Fatality Rate (WCB-2011)

Furthermore, in the United States, published statistic regarding to fatal occupational injuries shows construction industry with 775 numbers of incidents in the first rank. It is fairly certain that construction industry, due to having a majority of dynamic resources, could be more potential to embed unpleased accidents in it (National census of fatal occupational injuries in 2011, 2012).

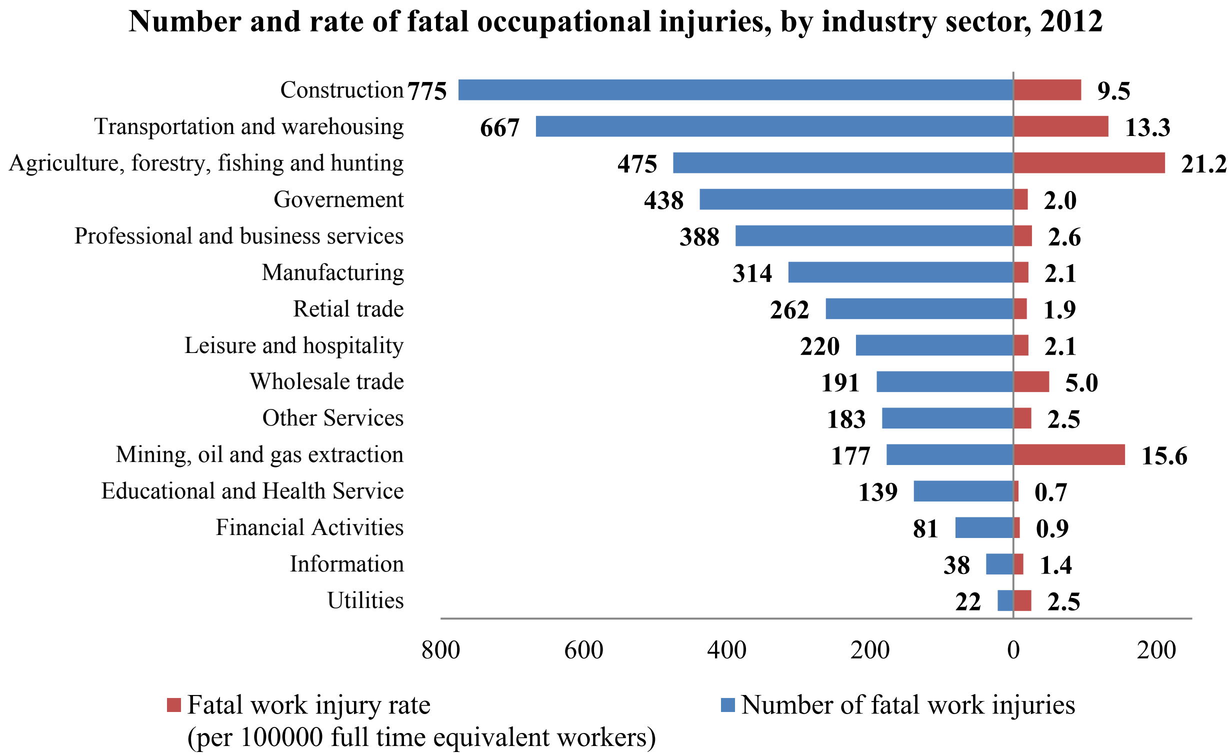


Figure 2-3: Number and rate of fatal occupational injuries (National census of fatal occupational injuries in 2011, 2012)

By narrowing down in construction industry statistics, it would seem that 18 percent of fatal injuries in construction industry are taken place due to strike by object or equipment (Figure 2-4). This category of accidents is mostly related to all types of contact collision between different types of equipment and objects. Heavy equipment, such as tower crane, excavator and trucks, are involved in major accidents which result in fatalities. Each type of contact collisions or accidents among these resources has economic losses for the construction industry in the best case, where it can be much worse if fatalities take place too.

Fatal occupational injuries for Construction Industry

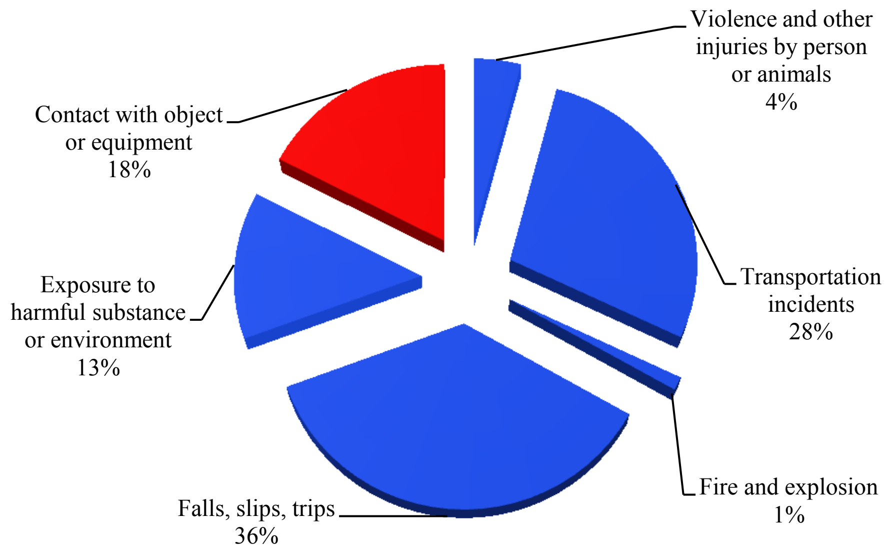


Figure 2-4: Types of Fatal Injuries on Construction Industry

According to revealed statistics, there were about 130 crane accidents to have happened between 1992 and 2001 in the United States (Kang and Miranda 2004), 216 fatalities have incurred averagely since 2003 by striking ground worker by equipment or other objects and 41 crane accidents resulting in death in Japan (Kawata 2007). In the United States, 151 accidents lead to mortality in 2009 due to collision between workers, object and equipment. These fatalities attribute to 18% of total construction fatalities (Marks and Teizer 2010). In spite of descending trend in number of incidents in construction industry in past decades, having an automated safety systems besides the published guideline can bring more benefits into construction industry, which will be discussed in further section.

2.3 Crane Safety Research Background

Mobile Cranes in North America is one of the most preferred equipment in construction industry for project participant, or in the same meaning, it is noticeable symbol of United State equipment culture (Shapiro et al. 2000, Peurifoy et al. 2006). Since mobile cranes become more deep-rooted in North America, there would be no surprise if the most of publications related to construction industry or site safety addressed mobile cranes as a main machine. However, tower cranes, the representative of construction industry in Europe, have increased in North America in the last decades (Shapira et al, 2008). Prior to evolving trend in tower crane usage, they were used only in projects when there was no choice, i.e. high rise building or congested area, but nowadays American firms have changed their traditional attitude to employ more tower cranes. Although mobile cranes configuration are more complex and the operating structures are potentially more dangerous than tower crane, underestimating of tower crane safety due to its vast coverage area could be useful (Shapiro et al. 2000, Peurifoy et al. 2006). Tower cranes operation is usually followed by carrying multi variety of elements in wide range of weight or dimensions, which makes job media hazardous (Neitzel et al. 2001).

Several researchers have studied tower cranes operation and probable factors or situation which impact on the safety of construction sites (MacCollum 1993, Hinze 1997, Shapiro et al. 2000). In 2009, Shapira and Lyachin identified the affecting factors based on four categories: project condition, human error, and environment and safety management and finally by assigning numerical weight into these parameters ranked them (Figure 2-5).

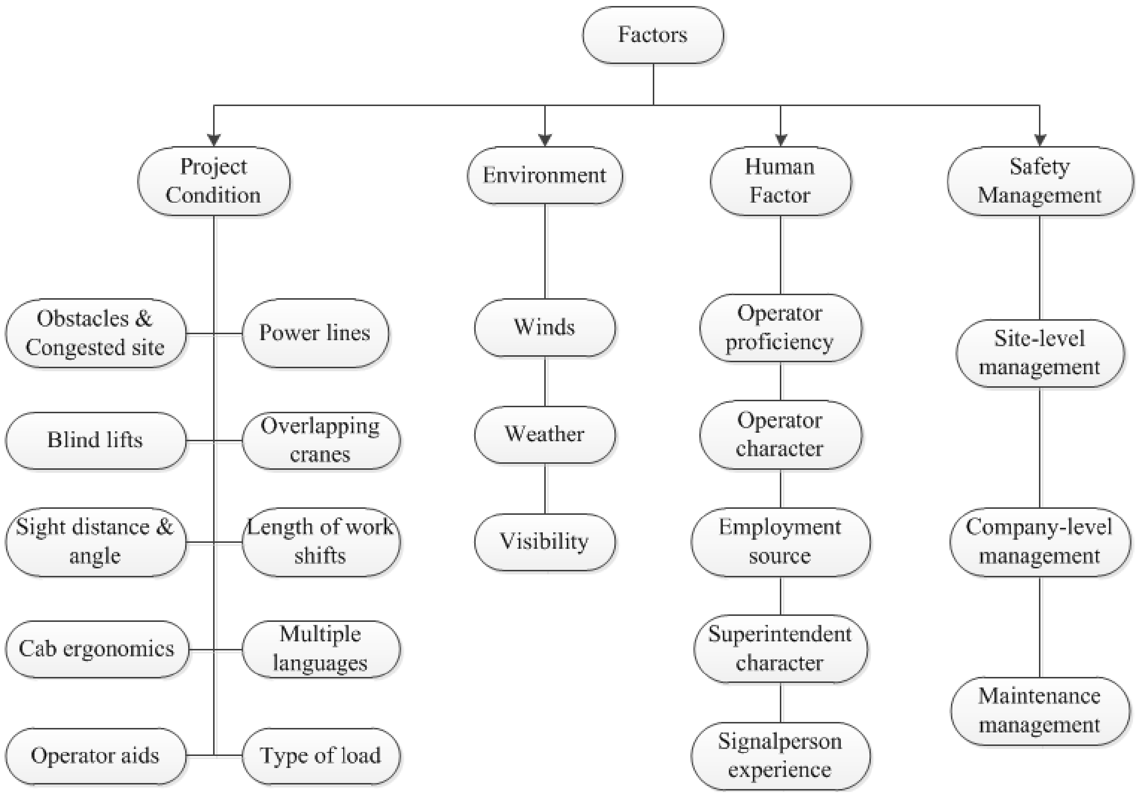


Figure 2-5: Affecting Factors on Crane Operation Safety (Shapira and Lyachin 2009)

They prepared list of probable factors through face to face interviews with experts and experienced managers, and subsequently degree of influence for each factors were found. As shown in the bar chart, degrees of influence for probable factors are depicted. Identifying and ranking affecting factor on tower crane operation were studied, and blind spot as one of important factor shows its significance role in tower crane operation (Shapira and Lyachin, 2009). Since the blind spots and miscommunication can cause contact collision and provide dangerous situations for workers or even an operator, the writers suggested applying more training hours and mandating variable guideline based on project type on involvers in activities can reduce fatalities rate in construction industry.

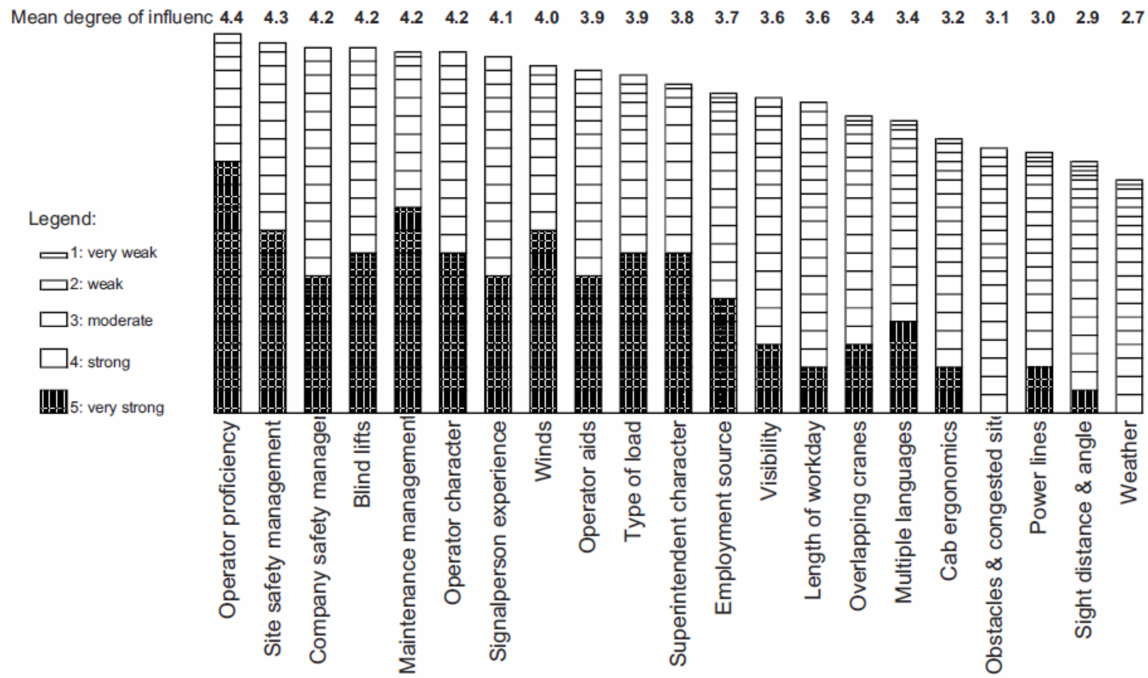


Figure 2-6: Degree of influence for affecting factors (Shapira and Lyachin 2009)

In another implemented study in Hong Kong, tower crane related accidents and also affecting factor in tower crane daily operation were studied. There are four important contributing factor found, including (Tam and Fung 2011):

- Carelessness or misunderstanding of participant
- Insufficient preparation
- Sub-contracting involves in tower crane operations
- Time limitations

Regarding to recent studies and statics, it is generally recognized that blind spots and miscommunication can be one of the most common reasons in crane accidents.

One of the tower crane advantages compare to mobile crane is a large zone of vision, since the cab operator is at the top in most cases (Shapiro et al. 2000). This wide range of vision grants tower crane operation more productive and safe, but ignoring blind spots impacts is unavoidable especially in the high-rise construction project. In order to address blind spots in crane activities, several probable situations have been identified when:

- Load, landing area, load's path and crane's path are not visible for operator
- Difficulty in estimation of relative distances between objects

As shown in Figure 2-7, in these five different circumstances, crane operator faces situation, which identifying load and its landing area, is obstructed by outer parameters. Figure 2-7a) depicts the situation, when hooking, unhooking and also the travel path of the load is hindered by obstructions. Many of construction sites are active in both day and night time, therefore having poor lightning condition in night-shift makes the operator visibility limited (Figure 2-7b). Another case can be caused by variance in light intensities, which takes time for crane operator to be adopted. As it can be seen in Figure 2-7c, in the gray shaded area (elevator or stairway box), the landing area light intensity change and consequently the loading operation is risky. Figure 2-7e and 2-7d shows unloading situation, which operator needs appropriate angle of vision in order to have precise installation or placement (Shapira et al. 2008).

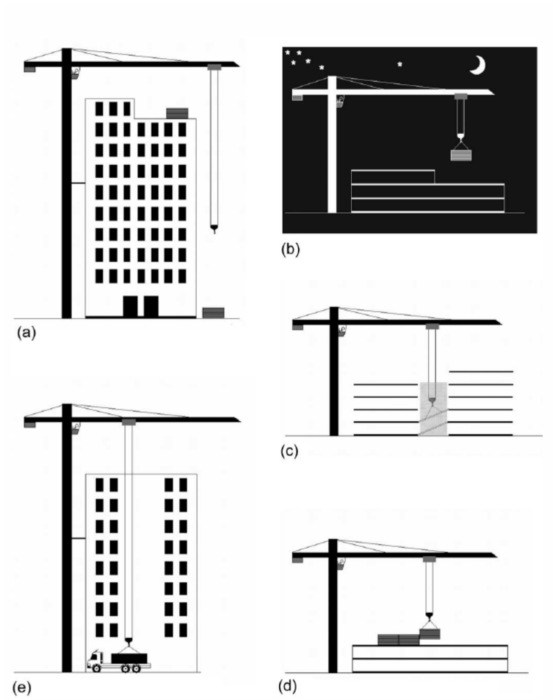


Figure 2-7: Load visibility from operator position (Shapira et al., 2008)

The Neitzel et al. reviewed all related factors which interact with crane operation in construction sites (Neitzel et al. 2001). They went through existing crane safety technology systems, to identify related injury in crane operation by reviewing frequent guidelines and standards in crane industry. Moreover these findings about concealed area in crane operation, Cheng and Teizer (2011) mentioned that restricted vision sight on ground activities could become one of the most accident causations. In 2006 Beavers et al. investigated documented files for Occupational Safety and Health Administration (OSHA) from 1997 to 2003 to highlight physical factors and causes in construction industry which resulting in fatalities (Beavers et al. 2006). In this study, the writers found the frequency of victims regarding to type of proximal causes. Victims were classified in four categories of: operator, rigger/laborer, ironworker and other.

Table 2-2: Proximal cause correlation with victim occupation in carne fatal incidents (Beavers et al. 2006)

Proximal Cause	Victims	Number of events (%)
Struck by Load		40(32)
	Operator	0
	Rigger/laborer	19
	Ironworker	9
	Other	10
	Unknown	2
electrocution		34(27)
	Operator	2
	Rigger/laborer	25
	Ironworker	0
	Other	6
	Unknown	1
Crushed during assembly/disassembly		15(12)
	Operator	3
	Rigger/laborer	5
	Ironworker	1
	Other	5
	Unknown	1
Failure of boom/cable		15(12)
	Operator	1
	Rigger/laborer	9
	Ironworker	1
	Other	3
	Unknown	1
Crane tip over		14(11)
	Operator	5
	Rigger/laborer	5
	Ironworker	0
	Other	2
	Unknown	2
Struck by cab/counterweight		4 (3)
	Operator	0
	Rigger/laborer	2
	Ironworker	0
	Other	1
	Unknown	1
Falls		3 (2)
	Operator	1
	Rigger/laborer	2
	Ironworker	0
	Other	0
	Unknown	0

Based on their findings, 67 victims were known as rigger or laborer, 18 were recognized as riggers and 49 as laborers form from the incident file descriptions. It can be concluded from their findings that the probability of accidents between moving load by a crane and other objects and equipment is higher than the other factors.

With the intention of defining possible tower crane related accidents, four different types of accidents have been defined as follow (Luo 2013):

1- Load and hook components falling
2- Load and crane components conflict with permanent obstruction
3- Load and crane components conflict with any potential obstacles
4- Clash between tower crane and other dynamic resources

Two significant reasons which are entailed in these happenings could either be due to lack of enough time for recognizing hazardous area (Fullerton et al. 2009) or misinterpreting of involvers in crane operation. Therefore autonomous tower crane safety system can help construction industry via providing real time information for either workers or operator, and finally reduce the fatality rate by minimizing the human-based misjudgment. Despite the other industries being ahead of construction industry for applying computer technology to improve safety and productivity, a swift improvement has been started in construction industry in recent years (Luo et al. 2013).

Improvement in information technologies and computer software draws most researchers' attention to utilize the new technologies for tracking the labors and equipment proactively with the aim of preparing the second chance, if other safety protection devices or practices fail. Several researchers have implemented a comprehensive studies on lift planning in different areas, including lift path planning, optimizing crane location regarding to its efficiency, capacity and workability (Hass and

Lin 1995, Al-Hussein et al. 2000, Zhang and Hammad 2012, Lei et al. 2013), but these studies are more focused in generating optimized lift plan and not mention about safety issues in lifting operation. In developed system by Al-Hussein et al. (2001, 2005), the procedure of crane's type selection and also locating points are utilized through using the existing information in the load-capacity charts of crane. The crane database which was named D-Crane includes lift-capacity of diagrams of different cranes manufactures and related geometrical variables as well. This system selects the crane which meets the lift capacity and also can be located on the jobsite by satisfying a set of constraints. With the aim of extending previous research, Hammad et al. (2007) utilized equipment workspaces to detect spatiotemporal collisions in a three-dimensional site layout In Lei et al. proposed methodology, the lift paths are checked automatically in project layout regarding to the crane's capacity, safety clearances and site constraints (Lei et al. 2013).Numerous researchers have also studied the effect of tracking technologies either on productivity or safety (Ergen et al. 2007, Fullerton et al 2009, Lee et al. 2012 and Li et al. 2013).

Tracking technology which use in proximity warning system could be categorized in image-based, range-based and global positioning system (GPS). Based on Ruff (2001), all of these technologies followed by limitations, such as weight and dimension, consistency in construction site and functional range. In 1993, Everett and Slocum equipped the crane boom with video camera (CRANIUM) to assist operator by transmitted signals on installed monitor in the cab, but transferred information could not cover entire area due to its fixed position (Everett and Slocum, 1993). Lee et al (2006) enhanced the safety technology system in crane by utilizing wireless video technology and RFID to transmit real time site images, pick and set point of the material in operator screen. Regarding to installed point of this camera system, operator has only the bird view of object and the top side is visible. Assisting the operator with a vision aid which reduces the hazard of blind lifting is common goals to all these researches, and subsequently improves crane safety and productivity (Chi and Caldas 2011 and Yang et al. 2011). Though, these image-based set made blind area apparent for operator but recognizing hazardous or restricted zone are still need operator judgment.

In following sections the current related studies on useable tracking technologies for construction activities and also integration of them into BIM model in order to improve project progress and safety monitoring are investigated.

2.4 State of Practice in Tracking Construction Entities

Over the last few decades, intelligent sensing technologies were deployed in construction industry for controlling and monitoring of the different processes. These technologies could be either use in construction or operation phases. These technologies draw most researchers' attentions for the sake of having automated data acquisition system in order to increase productivity and safety on construction sites. This section presents applications of popular tracking technologies which are mostly utilized and implemented in construction projects.

2.4.1 Global Positioning System (GPS)

In early 2000, positioning system has been used in construction industry. United States Department of Defence developed GPS system and make it completely operational in 1995 by locating 24 satellites in earth orbit. This system compromises of three major parts: 1) space segment, 2) control segment, 3) user segment. An overlapped coordinated satellite which is space segment, GPS devices attached on each equipment or object of interest as user segment and control segment which controls interaction and data communication among sensors and satellites (Ogaja 2011). Nowadays, GPS technology is recognized as one of the most useful technology in tracking public transport facilities and heavy construction equipment. The attached GPS receives the object's location from satellite and transmit the data to control segment through wired or wireless network. Later on, modified or raw data could be depicted on the map to visualize the equipment position in real time (Eecke 2010). Since GPS units need line of sight to constellation of satellites, they are more efficient in outdoor environment without obstacles. Various types of GPS units have been developed for different applications in construction industry. The GPS sensors are improved for their user by manufactures, which enable them to provide locations with high accuracy equipment (Cable 2010). Lee et al (2002) studied the effect of global positioning system (GPS) on crane efficiency in construction site. In spite of achieving acceptable results, utilizing of GPS was not considered practical due to high level of uncertainty. With passing the time and evolving in computer industry, the positioning system became more precise. In 2006, Kim et al. (2006) verified Kwon et al.'s (2004) investigation and concluded GPS usage could enhance safety in construction. In a short boundary of time, GPS has been developed and become operable in different aspects of construction industry, including locating and tracing materials (Caldas et al. 2006, Song et al. 2006), resource and safety management (Gong and Caldas 2008, Teizer et al. 2007). Several studies were also conducted on practicability of GPS usage to measure equipment productivity such as tower crane, trucks, etc. By 2002, Oloufa et al. (2002) used GPS technology for detecting the clash between construction equipment. With this aim, the system was implemented in unsafe condition where existing of human is not suggested, the wireless system transmitted the GPS data to central processor for identifying probable equipment collision. GPS accuracy varies between 1 cm, in case of using kinematic GPS, and maximum error of 10 m when equipment installed with general GPS (Caldas et al. 2004). Alshibani and Moselhi envisioned earthmoving equipment productivity by utilizing GPS and also Li et al. improved safety monitoring system in real time by integrating GPS and RFID technology in crane lifting process, but using RFID tag for each worker and track them during daily activity was not pleasant for workers due to private reason and also neglecting the probability of collision between crane and constructed building could be addressed as limitation with mentioned research (Moselhi and Alshibani 2007, Li et al. 2013)

2.4.2 Radio Frequency Identification (RFID)

RFID is another type of applicatory sensing technology in construction industry which has been become popular in recent years. This identification system includes RFID tags, reader and central management system. While waves emit from reader, each RFID tag respond to received signal and transmits its own unique ID for reader. RFID-based detection systems are usually applied for tracking construction materials. Many pre-fabricated or structural elements are embedded in with RFID tag in production line for making their track and installation more accurate and easier (Engineering News-Record 2008). In an implemented study by Akinci et al. (2002), the precast concrete parts were tracked in supply management process through RFID technology. Building elements could be tagged by RFID sensors and through scanning RFID sensors, RFID information will be used in integrated 3D model to have an updated model (Yoders 2008). This facility enables project controller, to check element or activity sequence order. RFID technology can be used in worker and equipment identification for the purpose of resource control (Sawyer 2008).

Studying on different aspects of RFID technology has been implemented continuously. It is currently using in quality management, collision accident prevention and automated data acquisition (Wang 2008, Chae and Yoshida 2010). Each technology has its own drawbacks, so integrating two or more types of sensing technology lead to improvement in accuracy and workability. RFID network has been used in construction industry to avoid contact collision between tower cranes (Gomez 2007). In 2010, Ko localized different construction element by proposing RFID based system in 3D model (Ko 2010). Furthermore, integration of RFID and GPS on construction was studied to trace precast tagged material and also for tracking labor in construction site in order to keep them safe from to be struck (Ergen et al. 2007, Li et al 2013).

2.4.3 Ultra Wide Band (UWB)

An Ultra wide band system is a communication network, which uses receivers and tags to communicate with each other via a large bandwidth and low power. The transmission of radios between tags and receivers enables the system to acquire 3D coordination of each tag position. The quick communication in the network increases the accuracy of 3D positioning system in any real time application. The published articles on UWB technology system show the accuracy range of 0.1 m to 2.0 m based on the system configuration. The basic pattern of UWB technology system for 3D tracking of project entities includes, one central hub, four receivers (need for synchronization) and transmitter tags for each interested objects (Ghavami et al. 2004). Application of UWB technology was studied on safety and productivity indexes in real projects, but the research area did not consider the effect of obstructive and occlusive elements during the study implementation (Cheng et al. 2011). The accuracy of UWB technology can reach up to 15 cm in circumstances where metallic objects are not in the proximity of tags and also direct line of sight from transmitter and receiver is existing (Muthukrishnan and Hazas 2009). In the work reported by Zhang and Hammad (2011), the crane is equipped with UWB tags and the spatial dimensions of the crane boom are calculated in near real time. In their study real time re-planning is deployed to prevent cranes collision when two cranes are working in the proximity of each other. Since construction equipment are the moving objects, considering the safety clearances for each moving entities can increase the accuracy of the safety systems (Zhang et al. 2012). In another research by Zhang et al. (2012), the safety issues on the construction sites are studied. They utilized BIM model and RTLS in order to check adaptability of the installed physical barriers with safety regulations. Moreover, they developed a fall protection safety system, by generating the dynamic virtual fences in BIM model and tracking the workers equipped with UWB tags. However the developed model of Zhang et al. (2012), utilizes the UWB technology and BIM model, but it requires the deployment of at least one individual UWB tag for each mobile resources, which increases installation and maintenance cost of such system. In addition, their procedure of exporting the file from Autodesk Revit file into Navisworks required additional time compared to the development made in this study.

The application of UWB technology was studied on safety and productivity indices on real projects, but the research area did not consider the effect of obstructive and occlusive elements during the study implementation (Cheng et al. 2011). Since construction projects are involved with interaction of several dynamic resources and these daily interactions make the construction environment congested, avoiding metallic objects and having available line of sight is impossible. On the other hand, most of the construction projects include many resources which may work in the indoor or outdoor environment. Hence, installing many tags can lead to high initial cost for projects and even can get more in the maintenance life cycle as well.

2.4.4 Video Tracking

Video surveillance utilization has been increased significantly in various sectors. It is now an implemented technology for the sake of security at airports, banks, casino and all government institutes. In practical, all the important divisions, equipped with video surveillance to improve safety and security in order to avoid illegal behaviours. Many industries now set up the wired or wireless network of camera for monitoring (Challa 2011). One of the fundamental requirements in order to use camera system is being capable of understanding and detecting the target over time. The procedure of object(s) detection and corresponding location(s) by using the camera in near real time is called video tracking. The advancement in image sensor technology and also computational power of processor in last decades led to attraction of researchers' attention to develop new algorithm in video tracking utilization.

- Vision-Based Object Detection

Detection and recognize of objects play a significant role in localizing project elements in 2D. In this part a review on different computer vision algorithms will be presented. The principle goal in object detection is recognizing and classifying objects (e.g. face, equipment) through the image property which are mutual for all object in one category. Object classification can be implemented through defining a standard which match to several appearance of the object related category. The most common features in object detection process are color, shape and motion behavior. Haar-like features methods have been used in object detection, which owe its name to Haar wavelets. The main idea in this approach is defining rectangular box and considering discrepancy in image pixel intensity between the neighbouring boxes (Viola and Jones 2001, Lienhart and Maydt 2002). Haar-like features can be obtained through training images for several times. Machine learning could be trained with compatible algorithm to learn to recognize different pattern of images. For instance, Adaptive boosting algorithm is used in standard Haar-like features for face recognition (Viola and Jones 2001). The vertical and horizontal Haar-Like features are variant over turning. It means standard Haar-like features is not capable of detecting and distinguishing rotating object, thus not being sensitive with angle changes. To overcome these drawbacks, 45 degree Haar-like feature was proposed in order to improve object detection process (Lienhart and Maydt, 2002). Histogram of Oriented Gradients (HOG) as the other well-known method for object detection is implemented by separating each image into small joined zones which named cells. Then, histogram for each block could be generated by compiling each cell to count number of gradient directions or edge orientations happenings. The advantage of HOG feature against Haar-like feature is studies and presented by Dalal and Triggs, in 2005. In their study HOG feature with support vector machine (SPV) training algorithm was trained for human recognition (Dalal and Triggs 2005). The accuracy and speed of human detection process was increased by integrating Adaboost as a learning machine with HOG features (Zhu et al. 2006).

Color property is another valuable feature for distinguishing of an object kind. A color histogram is using in image processing tools for identifying objects with specific color (Swain and Ballard 1991). In spite of being easy to calculate and consistent with different angle rotation, which are the good advantageous for object detection, color dependency and shortage of spatial related data are the main limitations in this procedure. For example color histogram can be equal for a pair of image which is taken from different objects. The integrated color histogram process has been used in tracking system to distinguish pedestrians or hockey players (Sugano and Miyamoto 2009, Lu et al. 2009). However a pedestrian could not be detected by color histogram accurately due to their variety in clothing. In 2009, Lu et al. used Haar-like feature in order to distinguish targeted object and color histogram implemented separately for tracking the identified objects (Lu et al, 2009).

Eigenfaces is a well-known feature which uses eigenvectors for human face detection. This algorithm was proposed in 1987, and generally implemented through principle component analysis (PCA) or Fisher's linear discriminant (FLD) algorithms (Turk and Pentland 1991, Belhumeur et al. 1997). The standard template is attained by measuring two arbitrary variable relative variances, which are pixels and subsequently the worthless parameters will be eliminated. This feature can extract necessary information for color and shape according to value of vectors which are arranged based spatial position. Background subtraction, which is another image processing techniques uses an image background in its further analysis (object detection). This method is mostly applicable for moving object recognition process such as car, human and etc. (Mcfarlane and Schofield 1995, Stauffer and Grimson 2000, Li et al. 2002). Data from static cameras are used for objet recognition through analyzing discrepancy between foreground images as a reference and further frames.

In 2002, Stauffer and Grimson proposed the visual monitoring system for movement tracking by using the mixture of Gaussians theory in adaptive background subtraction approach (Stauffer and Grimson 2000). It generates the model based on multiple Gaussian distribution, which background pixels value were its input for identifying object position from reference and current frame variances. Background subtraction approach does not need lots of computational effort since it can recognize any of mobile entities simultaneously. All the motion feature-based methods are impotent for object type classification. In proposed method by Chi and Caldas, construction dynamic resources were categorized and detected. The foreground blobs were extracted by background subtraction in order to train some necessary characteristics (Chi and Caldas 2011). However, the proposed system was unable to discriminate between labor and non-labor human and also error-prone in illumination variation.

- Vision-Based 2D Tracking

Although the discussed part in the above part aids us to distinguish an object in each frame, the extracted object is not followed by specific information. Since all gathered information are only for individual frame, understanding the path which moving entities pass through a time is not doable by using object recognition method. In other words, having 2D positions of objects in an individual frame would not be efficient in object trajectory. For that reason, utilizing an algorithm to track the detected object in sequential frames based on motion pattern is necessary. In continue, three different classes of 2D tacking methods, contour-based, Template-based, and point-based will be reviewed.

- Contour-based Methods

In this method, the detected object is depicted by surrounding lines or contours, in which obviously, the object situated in the closed silhouettes. The method uses the acquired information, which is the closed boundary from previous frame, and then the model estimate the current location of encompassed region in present frame (Nguyen 2002). Since this method detects object's edges for generating contour, easiness in implementing and also being consistent with variation in lightning condition could be counted as its benefits. Normally, the counter-based method can track entities correctly in spite of any variation within the regions, but it shows weakness for the images with no clear edges, to analysis and gets feature information. Parameterized and non-parameterized contours, which are in subcategory of counter types, were used by Nguyen (Nguyen 2002).

Generally, parameterized based method is used more for object tracking. The contour can be estimated by either a parametric model (B-splines) or make the energy function minimum as much as possible. In the first one, the method fit the B-spline curve to object's edges and then B-splines will be tracked by using Kalman filter or Monte-Carlo. In other method which is typically addressed to as "snake", the silhouette detection is performed by reducing the internal and external energy to the minimum amount for the contour and finally leads to generate of contour's outline (Yokoyama and Poggio 2005,Tsechpenakis et al. 2004).

- Template-Based Method

In general template states the shape of the objects (Yilmaz et al. 2006). Hence, the template-based method refers to the method which uses the appearance and shape of the object for tracking. In this method the region which properly represents the forms of the objects is used for extracting necessary information such as color and texture. The acquired information will be used further to update and fine the objects in subsequent frames (Marfil et al. 2007, Schreiber 2008). Since color is a good indicator for distinguishing partial occlusion in individual frame, color histograms can have an effective role in region-based methods (Marfil et al. 2007). The basic approach of template-based tracking is identifying the best matches with the reference region which is already given to the algorithm in first frame. There are several algorithms have been proposed by different researchers, which have some advantages and disadvantages when compare to each other, and may suitable for different purposes (Lucas and Kanade 1981, Isard and Blake 1998, Marfil et al. 2007, Ross et al. 2008).

- Point-Based Method

In this approach, points are used as a representative of objects. Instead of using regions or templates, few points of objects are chosen to be tracked in successive frames (Yilmaz 2006). Point-based tracking methods are mostly useful for tracking very small objects which can be marked by single point (Yilmaz 2006). By enlargement in size of an object, more points may be needed for effective detection of the object in consecutive frames (Yilmaz 2006). Several researchers proposed multipoint-based algorithms for tracking of small objects such as tiny particle in a tubular reservoir (Shafique and Shah 2003). Stereo Geometry

As explained earlier, video tracking cannot compete with other 3D technologies, unless the 3D information can be provided. According to Hartley and Zisserman providing the 3D position information by stereo geometry needs necessary primary steps (Hartley and Zisserman 2004). Before starting the 3D video tracking, the intrinsic and extrinsic parameters of camera should be extracted. In order to this, several standard calibration tools are provided which, reveal intrinsic parameters of camera such as, the focal length, radial distortion and tangential distortion (Heikkilä and Silvén 1997, Bouguet 2004). After the calibration procedure, the camera coordinates should change to world coordinates. The most known algorithms for this purpose are SIFT (Scale-Invariant Feature Transform) and SURF (Speeded up Robust Features) (Lowe 2004, Bay et al. 2008). While SIFT algorithm reveals information much more accurate, but SURF has more computational efficiency (Bauer et al. 2007). Several robust algorithms are also introduced to improve SIFT and SURF (Torr, 2002). In next step, essential matrix (E), should be identified to find relative pose of two cameras (R, T).

Several studies have implement on construction site by applying stereo vision system. The stereo camera system has been utilized to capture 3D for the purpose of progress monitoring (Chae and Kano 2007; Son and Kim 2010; Golparvar-Fard et al. 2010). Son and Kim (2010) utilized stereo vision camera to capture 3D data for distinguishing structural elements. In another work, Golparvar-Fard et al. (2010) used stereo geometry to provide the actual model of project through daily progress photos. Woo et al, developed stereo vision system to obtain 3D position of construction entities during the daily tasks. In this study, Park et al.'s methodology is used for identifying workers for the purpose of safety (Park 2012).

2.5 Building Information Modeling (BIM)

Building information modelling is a functional process for developing and generating the digital representation of building elements to facilitate the design, construct and operation process during the life cycle. A shared knowledge platform for exchanging information in BIM eases the interoperability between the stakeholders to update and modify information at the same time (NIBS, 2007). The application of BIM in the architecture/engineering/construction (AEC) industry has been evolved since last decades by providing coordinated, consistent platform for users (McCuen, 2008, Eastman et al. 2008).

The first goal with adoption of BIM is to generate an inclusive representation of building which contains design, specification and details in an individual central model (Krygiel et al., 2008). This model considers all functional associations between different elements. For example, the wall and the door has their own specification and characteristics in BIM model which completely recognized separate from each other, but in 3D model the wall and door could be represented by drawing multiline which are inherently the same (Fu et al. 2006). Each elements in BIM model has the unique ID number which enables user to extract necessary information and integrate with different decision platform for different purposes. BIM role is not limited to provide useful information relating to quantity, cost and type of materials but also prepare an analytical environment in order to implement data processing depending on required objectives (Chen et al. 2013). The integration of BIM model and RFID was implemented by Motamedi and Hammad in 2009. In this study the facility mangers as an end user of this application could read attached tags data label, which already were imported through BIM model.

The 3D BIM model could be integrated by time as a fourth dimension. The 4D BIM model enables the project participants (architecture, designer, contractors and owners) to have a visual representation of project progress in different intervals. In addition, 4D BIM models can be used by different project management divisions. 4D BIM model could be used effectively for planning, resources allocation, safety and also construction workspace management (Chavada et al. 2012, Zhang et al. 2012). Workspace and resource allocation were implemented within 4D BIM model to assist planner team to identify possible conflicts (Wang et al. 2004, Dawood and Mallasi 2006). Moreover, a few number of commercial construction management software such as CommonPoint and Synchro integrated the BIM model with time as a fourth dimension (Common Point Inc 2007, Synchro Ltd 2007).

BIM has been extensively used in early stage of the project, especially in design phase in order to have more effective cooperation and communication. There are also lots of research have been implemented to advance BIM application in construction industry (Lee et al. 2012, Zhang et al. 2013). Lee et al, developed tower crane navigation system which provides position of lifting load in real time by using various sensors in three-dimensional building information model. In this proposed system, operator has the capability of seeing moving object in 3D BIM model in real time (Lee et al. 2012). Based on findings related to this study, 2D illustration of the views were more comprehensible than 3D. In addition, it was highlighted construction management process would profit if the model could be updated as the construction activity and project progressed. In another study by Hasan et al. (2012), weather information was integrated in BIM model to control the crane stability while it is in operation. In the proposed framework, effect of wind direction and speed will be visualized into BIM model to assist the lift planner for designing the lift plan procedure efficiently. The BIM model also was merged with safety practices by OSHA to identify hazard situation for preventing fall related accidents (Zhang 2013).

2.6 Work Space

Construction projects are always followed by different resources. In other words, construction industry is meaningless without its dynamic resources. Each phase of projects is delivered by direct or indirect interaction of these entities. One of the most effective factors that effect on project delivery time is the available spaces for active or inactive resources (Dawood et al. 2005). Sometimes concurrent tasks and poor planning for required work spaces could hamper the progress of activities in construction projects. Activities on construction projects are commonly need several trades at any time interval to be accomplished. In addition to resource management, assigning separate workspaces such as: working, equipment and storage space makes work space management is important as well. The work space management should not be underestimated due to its potential influence on project productivity (e.g. delay and stand by equipment) and site safety issues (Chavada et al. 2012).

Construction planning and scheduling techniques are mostly useable for planning the project activities and resource allocations. In spite of some commercial software which helps the planner to visualize the sequential of activities, they are not efficient tools for work space management approaches, since the work space management tools need organized structure in order to identify, control and check workspace clashes (Dawood and Mallasi, 2006). To overcome these issues, utilizing visualization tools such as 3D or 4D can be helpful in workspace management.

- Activity Workspace Management

The term activity workspace management refers to the procedure of planning, controlling and monitoring workspaces conflicts on construction sites (Chavada et al. 2012). This process includes the steps of generation, allocation and interference detection of workspaces during the project daily activities. Thabet and Beliveay studies the workspace effects on construction projects, and realized that analyzing of the workspaces could avoid rework and delay in construction process (Thabet and Beliveau, 1994). In their proposed framework, AutoCAD environment was used for allocating needed spaces into correspond activities. In 2002, Guo presented a methodology to manage conflicts between different tasks. The writer found the required spaces from AutoCAD environment by considering spatial requirements of each activity such as, material storage or temporary facilities (Guo 2002). Although the proposed approach dealt with probable situation in projects, it could not be updated dynamically due to lack of automaticity features. To overcome this limitation, Akinchi et al. presented a methodology to generate workspace by using "4D Work Planner Space Generator" automatically (Akinchi et al. 2002). The methodology used spatial requirements from a known product breakdown structure (PBS) through the 4D CAD model. The given data later used in product space planning to link tasks and related spaces together. In developed model by Dawood and Mallasi, workspaces are modeled and their congestion quantified through critical space-time analysis (CSA). By embedding workspaces in a computerized tool PECASO (patterns execution and critical analysis of site space organization) site managers can assign and identify possible conflicts in 4D model (Dawood and Mallasi, 2006). In 2009, Moon et al, proposed a new approach for workspace management. In their study, the process of workspace allocation is implemented via semi-automatic method based on resource supplies (Moon et al. 2009). In continue of these developing studies, Chavada et al. proposed and developed the visual analytical method for generation and conflicts detection of the activity workspaces by integrating the schedule and BIM model in a 4D/5D environment (Chavada et al. 2012).

2.7 Summary

Nowadays, safety issues are considered as one of the most significant part of project management plan and many well-run organized construction companies execute the safety plan in their projects. Since construction projects are dynamic complex including many objects that are continuously in interaction with each other, the likelihood of an unpleasant incident happening is quite high. Tower cranes are one of the most popular lifting equipment move the load over the construction site for several purposes. Due to their capability of lifting different types of load and having a large coverage area, the moving load has potential to come into contact with different project entities and cause fatalities, accidents or property damages. Although many guidelines and practices have been published to improve safety conditions on job sites, making the second chance for workers who may be distracted or not enough aware about their surround situation is necessary. Applying tracking technology on projects can improve the workers safety during the daily tasks. Lately, GPS, UWB and RFID technologies have been deployed in several project management applications to track construction entities. Since GPS technology needs out door environment, it is more appropriate for outdoor resources such as heavy equipment. UWB and RFID are most suitable for tracking materials in indoor and outdoor environment respectively. Although they have also been deployed in several studies for tracking the workers and equipment, related costs for installation, maintenance and removing the wireless network have not considered for a real congested project. In spite of the positive performance of above technologies, neglecting the workers privacy and related costs may disappoint contractors to utilize them in projects. Moreover, recent related studies in this context, utilized safety algorithm in 4D simulation software such as Autodesk Navisworks or game engine, e.g. Unity. These software systems are particularly useful for simulation and do not have the drawing options in order to edit or modify models. Therefore, these models should be updated in BIM model (Autodesk Revit) and be exported to the simulation software, which is time consuming and accordingly does not suit the nature of the developments made in this study.

The developed safety model is expected to offer improvements over those developed recently by others. This is attributed to its near real time 1) definition of workspaces and related localization of resource position, and 2) crane load location using

GPS technology. Development of safety model in BIM model (Autodesk Revit) will increase, in comparison to other models, the speed of clash detection since it does not require data transport from one system to another.

Chapter 3: Developed Model

3.1 General

This chapter provides a detailed description of the proposed model. The main module and sub modules of the research model are covered throughout this chapter. The main objective of this study has been set for the development of proximity detection system to improve safety on tower crane operations, while using least number of tracking sensors. In order to achieve this aim, BIM model is used as a platform for integrating necessary information regarding the tower crane's load position and positions of project entities (Figure 3-1).

In the following sections, the main module and its four sub modules are explained and also the inner interaction with BIM model is illustrated. First, 4D BIM model generation algorithms and the related advantages are described. Then, the work space generation steps, requirements and adopted 3D video tracking system are described to clarify how occupied area can be revealed in BIM model. Finally, the integration of the proactive tower crane's load tracking system and BIM model is demonstrated in detail.

3.2 Proposed Model

The proposed model of the safety monitoring system is depicted in Figure 3-1. This framework embraces four sub modules which are shown in four dotted boxes. As can be seen in Figure 3-1, the 3D BIM model is the main part of the framework, as it will be used to merge all the information. The 3D BIM model is responsible for collecting and analyzing necessary construction data including updated schedule, workspace requirements, hooks locations and 3D spatial information from video stereo camera system. The model also executes the safety monitoring system. The GPS data acquisition sub module captures the hook and load coordination in real time while the tower crane is in operation (Figure 3-1b). The captured data is then transferred to the BIM model in order to implement further calculations. Since the main objective of this study is to implement the proximity safety monitoring system, all of the involved entities which may be struck by the hook should be defined and tracked. Three functional sub modules will be explained to answer the research question, "How to detect and identify the involved static or dynamic entities in tower cranes proposed safety system, while using the minimum number of tracking sensor technologies."

The first step is to integrate the updated schedule with the 3D BIM model. This provides a visual demonstration of all existing structures and facilities. This updated model shows new constructed elements or facilities which may not have existed in the initial 3D BIM model. Updated 4D model can provide all existing static obstructions which should be considered in tower crane daily activities.

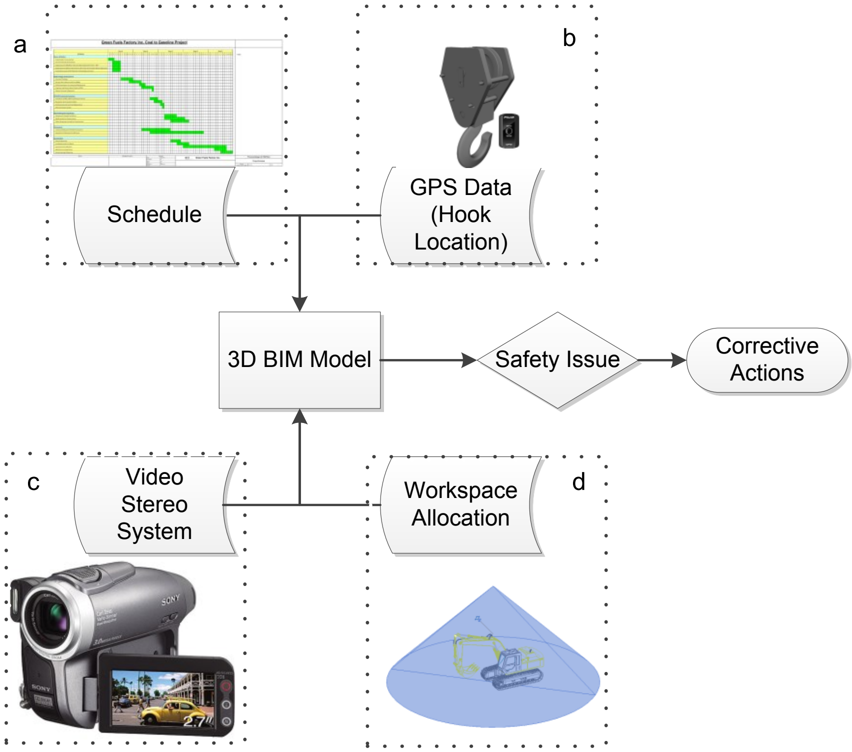


Figure 3-1:Schematic flowchart for proposed model

Time as a fourth dimension enhances the BIM model to visualize the completed construction activities as revealed elements in BIM model. For instance, columns installation or framings are activities which can be demonstrated in 3D BIM model. Those elements are not created in the 3D model of the earlier design phase, however, they will appear when the corresponding activities are executed (Figure 3-1a).

Although the 3D BIM model is updated to identify which elements or facilities are constructed in a project, but in some situations temporary structures are not reflected in the 3D model. Moreover, the personnel and other mobile equipment should be tracked during daily activities for the purpose of safety. Hence, in third sub module (Figure 3-1d), allocated workspaces are utilized to represent the occupied spaces by all of the equipment, workers or mobile elements involve in daily tasks. This feature enables the safety model to track objects locations in real time. Those locations should be defined as dangerous areas if the tower crane's load passes through or near. The sub module generates workspaces based on the pre-defined required area for crews, equipment, storage areas of material and any paths reserved for specific activities. This sub module assumes that all the information for assigning the workspaces is available.

As a routine behavior, it is possible that labors abandon the pre-defined workspaces for different purposes. On the other hand, this study has set its main goal to use the least number of tracking technologies to overcome the limitations of previous studies. Therefore stereo vision camera system is deployed to acquire 3D coordination of workers (Figure 3-1c), when they are inside or outside of the workspaces. The 3D information is acquired from Park et al.'s methodology for further usage in BIM model and safety detection system (Park et al. 2012). The 3D video tracking method is utilized in this methodology to support system for detection of workers when they are not in the workspaces.

After the integration of all sub modules into BIM model, the safety detection system can be executed. In the safety check algorithm, constructed elements, defined workspaces and also workers which have been tracked by stereo camera will be identified as dangerous area, and the relative movement of tower crane's load will be compared in real time.

3.2.1 BIM-based Scheduling Model

Fundamentally, 3D BIM model includes physical and functional characteristics of model's element as a shared knowledge resource for life cycle of project. In this research, BIM model is one of the resources, which is used to collect required information for identifying potential obstructions. Since, 3D BIM model only visualize three principal spatial dimensions (width, depth and height) of designed model, it is integrated with the time as the 4th dimension to be capable of reflecting the construction schedule effect on BIM model changes. Therefore, integrating 3D BIM model with the time as a fourth dimension to have a visual representation of project progress is necessary. In order to reach this objective, as it is depicted in Figure 3-2, BIM model (Autodesk Revit 2014) should be linked with schedule. Usually planners try to break total works into lowest level to reach deliverable work packages. For example, in residential projects, either steel structure or concrete structure, the project planner assumes that installing or casting columns as a work package, and then breaks it to smaller tasks based on the defined zone, axis number, etc. Therefore, in the first step, the 3D model elements are mapped for corresponding work packages in the planned schedule. These linked elements will be utilized further to illustrate constructed parts or accomplished activities in 4D BIM model.

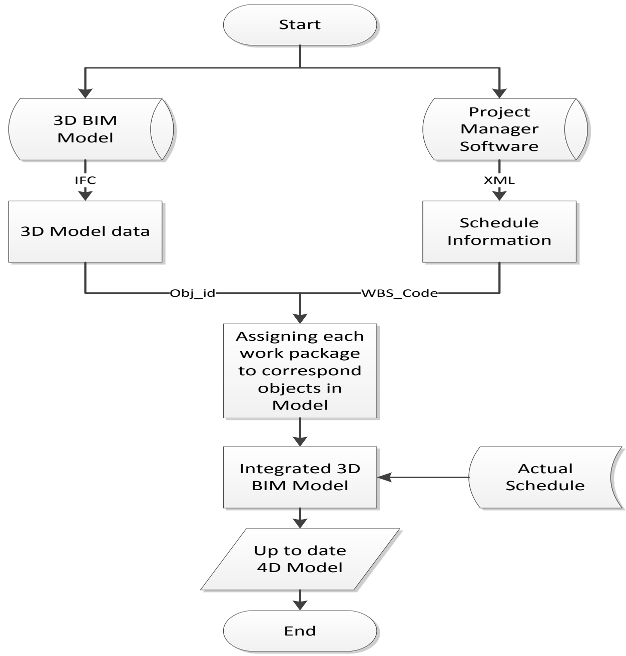


Figure 3-2: Integration of the 3D BIM model with schedule

As each object or element in BIM model has its own individual information, similar objects in term of application should be grouped into one category in order to be consistent with the work packages in the planned schedule. Since the 4D model is going to be used in safety monitoring system, the model should be updated daily. Existence of constructed or un-constructed elements should be gathered from the progress status of tasks, which would be in not-started, in-progress or finished conditions. Due to this reason, 4D BIM model should be updated based on the actual progress of the project.

Each element or defined group of elements in Revit Model has its own unique ID, which makes them distinguishable. On the other hand, each activity or work package in XML export file from Microsoft Project (MS Project) Office is defined based on single ID number, which makes the mapping procedure doable in programming languages. As shown in Figure 3-3, two screen shots from Autodesk Revit software and MS project are merged to show how same objects have different ID in BIM model. In the same way, each activity has a unique task ID which is used in the linking procedure.

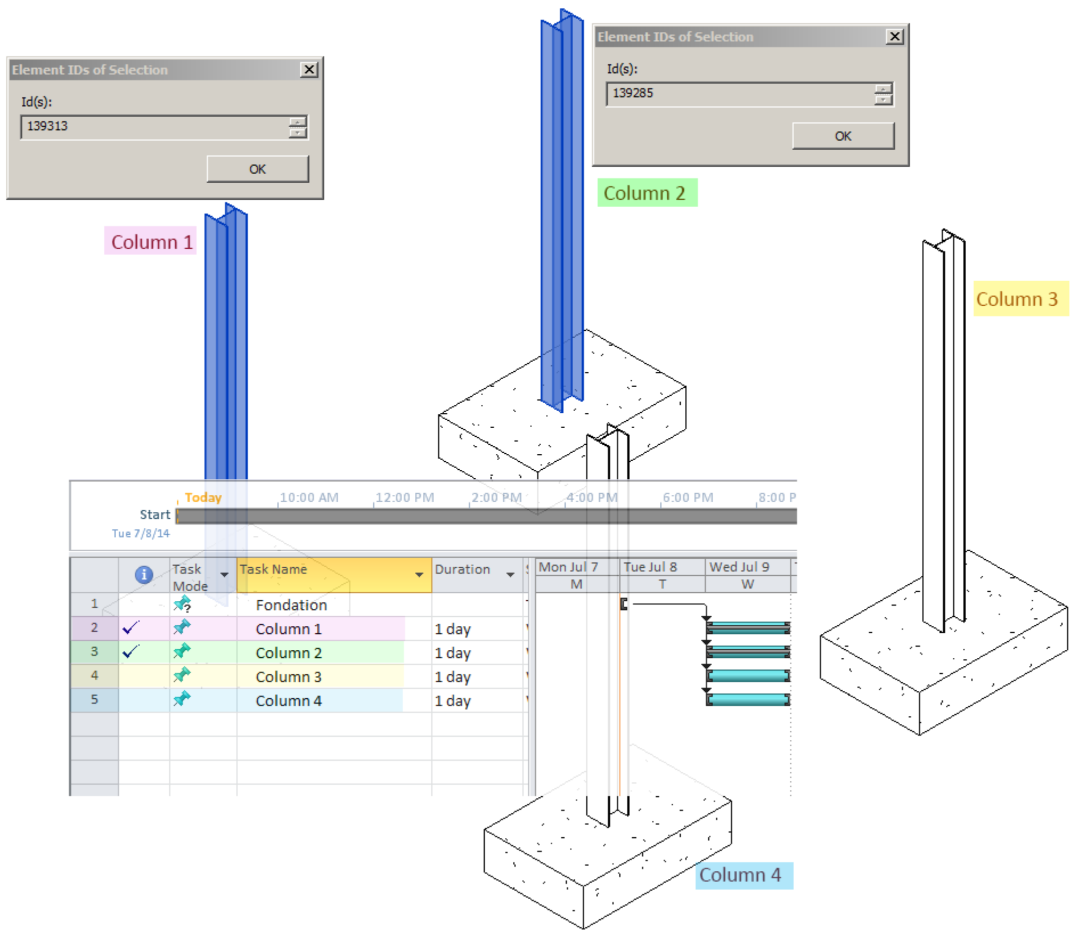


Figure 3-3: Addressing the activities in schedule to correspond element in Revit

3.2.2 Work Space Generation

Once up to date BIM model is built, the process of work space generation could be implemented to identify areas occupied by workers or temporary equipment in order to increase job site safety during the tower crane operations. As discussed earlier, GPS, UWB and RFID technologies can be utilized for tracking of entities on construction sites, but existing limitation with each type of tracking technology could decrease their efficiency and applicability on real projects. GPS technology is mostly utilized in outdoor environment and needs clear line of sight to satellites. Moreover, GPS and RFID need wireless network for tracking individual workers or equipment. Since construction projects include many daily activities, deploying wireless sensor network on interested objects can lead to increase in installation, maintenance and removing costs (Park 2012). In this study, 3D workspaces are mainly used for defining volumes which are not allowed to swing a load over, in view of safety guidelines.

According to Table 2-1, there are several types of workspace classifications that exist. In this approach, the classified workspace type by Wu and Chiu (2010) is used due to its compatibility with construction projects. The above selection of workspaces not only considers the daily activities and building components but it also illustrates temporary occupied spaces by equipment or hazardous materials. These defined workspaces will be used further in tower crane's safety proximity detection system for identifying workers or dangerous area.

Table 3-1: Workspace Type Classification (Chavada et al. 2012)

Rilley and Sanvido 1997	Guo 2002	Dawood and Mallasi 2006	Moon et al. 2009	Wu and Chiu 2010	Chua et al. 2010
Layout area	Working space	Product workspace	Installation space	Path workspace	Process space
Unloading area	Storage space	Process workspace	Prefabrication space	Material workspace	Resource handling space
Material area	Waste space	Equipment space	Transfer space	Laborer workspace	Product space
Storage area	Set up space	Equipment path	Loading space	Equipment space	Interdiction space
Personnel area		Storage path	Safety space	Site layout workspace	Usable space
Staging area		Path space		Building component workspace	Dead space
Prefabrication area		Protected space			
Debris area		Support space			
Hazard area					
Protected area					
Work area					
Tool equipment area					

The workspaces allocation flowchart is implemented in 4D modelling environment which includes the time-dimension to depict actual project status (Figure 3-4). As a result building elements and also ongoing activities are used for workplaces generation at any particular day. On the other hand, 4D BIM model facilitates the procedure of workspaces allocation for materials storage and equipment as well. In this process it is assumed that the user has all the workspaces requirements (Dimensions, shapes and locations) for construction methods. This data will be used further to generate bounding boxes through a developed plug-in within Autodesk Revit. A bounding box will be generated as a consequence of inserted information in Revit model.

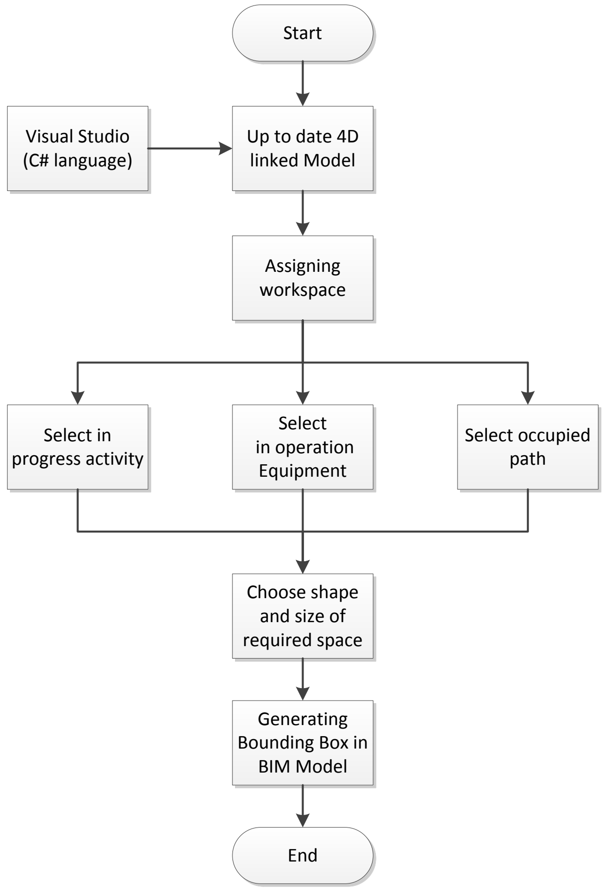


Figure 3-4: The framework of workspaces allocation

3.2.3 3D Tracking of Construction Workers

3D tracking of project entities could be implemented in several ways. GPS, UWB and RFID are the most familiar technologies which have been used in many industries, but according to literature applying these technologies in construction site, especially in congested area, take a lot of expenses for installation and maintenance cost. In this research workspaces are used to identify and locate the occupied spaces by equipment and works. In other words, workspaces are preferred to be detected instead of individual worker or equipment. Since these workspaces are static for construction activities and not having the automatic updating features, considering another tracking method seems demanding if workers leave the workspaces for different purposes. To achieve this goal, the proposed framework by Park (2012) is used to acquire 3D information of workers (Figure 3-5).

Before starting the 3D tracking of entities in construction sites, definition of objects of interest is necessary. In the proposed framework by Park (2012), construction workers who wear safety vast and hard hats are aimed to detect on the basis of three kinds of image features: motion, shape and color. The background subtraction algorithm uses motion-detection and the shape features which are already detected through training of HOG features and SVM. After the object detection process, the 2D algorithm is used for defining a zone of interest on current frame in order to track objects in later frames. Each detected region in the first step has its own independent information based on the features of an object category. Consequently, the tracking step uses the visual patterns and motion from the delivered outputs of first step for tracking the object in succeeding frames (Park 2012).

In their research, three different methods of 2D vision tracking are compared in a way to select the most effective and consistent method to construction sites conditions. As a result, the template-based method was identified as the best approach for tracking of construction workers (Park et al. 2011).

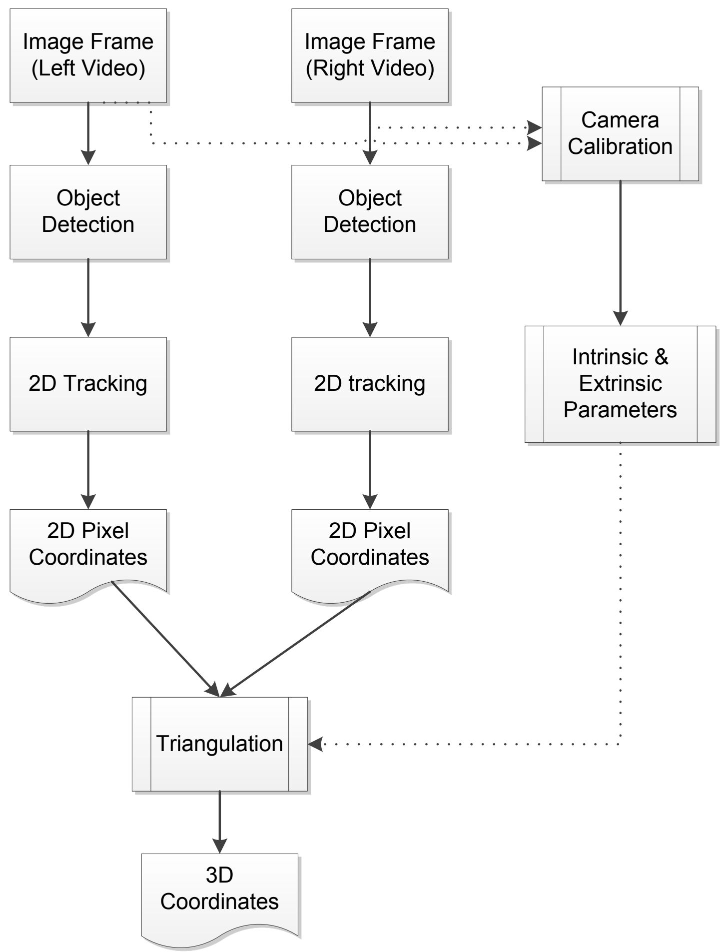


Figure 3-5: Proposed framework for 3D tracking of construction entities (Park et al. 2011)

Until now, the 2D tracking and object detection can only be utilized for localizing the object of interest in 2D for each camera frame, in which lack of the depth information still exists. To overcome this deficiency, stereo camera system was used to acquire 3D spatial information. They used two fixed cameras with several meter distance between them. After the installation of camera system, instinct and extrinsic parameters of each camera are extracted to set the geometry of camera system (Figure 3-6). As shown in Figure 3-6, the intrinsic parameters belong to each camera while extrinsic features are related to interaction of two cameras. The epipolar geometry and two found centroids were fed into triangulation algorithm and 3D coordination of object is identified (Park

2012). The obtained information for moving workers is appended into BIM model for proximity monitoring.

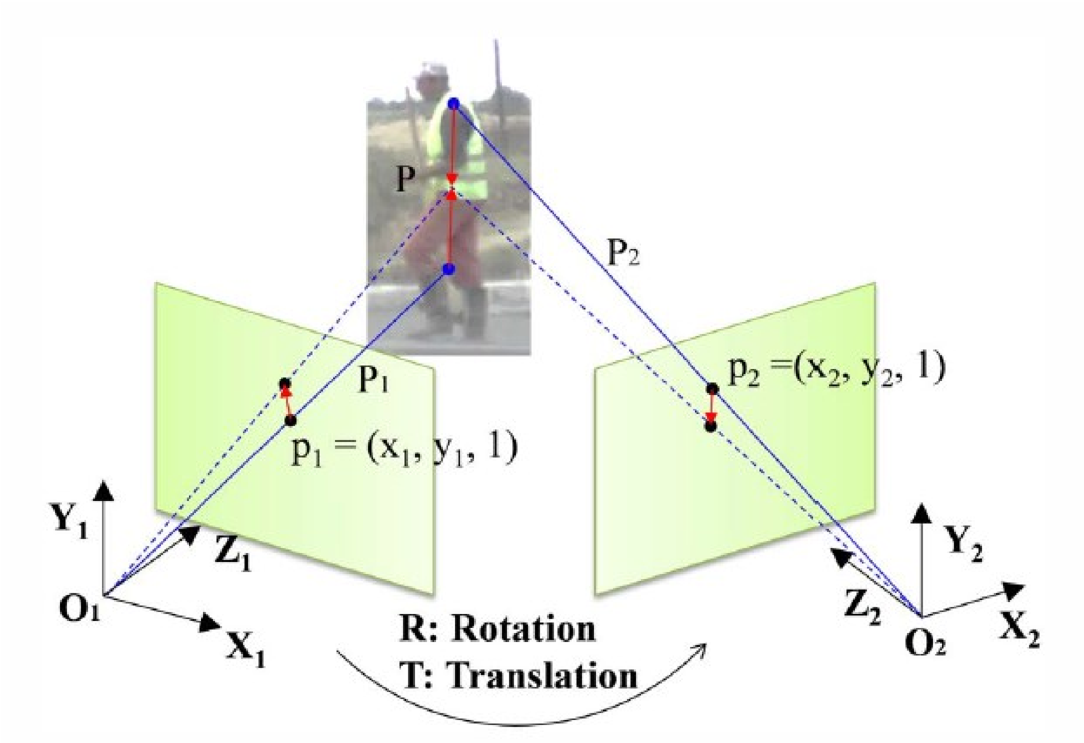


Figure 3-6:Epipolar geometry and centroid transfer (Park et al. 2011)

3.2.4 Acquisition of Tower Crane's Load Coordination

The main goal of this study is to improve the safety condition in construction projects, while utilizing tracking devices efficiently. The system alerts the crane operator by sending a warning message when swinging loads are within close proximity of project resources. Several tracking technologies can be utilized in order to find crane's load location, but GPS unit was preferred for this purpose due to the following reasons (Ruff 2001 and Teizer et al. 2007):

- Low initial cost

- Functional on any outdoor sites
- Minimal required infrastructure

To acquire the hook's position, a GPS devise is attached to the tower crane's hook. In GPS locating system, the receiver measures the transmitted ranges between the GPS unit and satellites which have the known coordination and then the GPS position is identified (Figure 3-7). As shown in Figure 3-7, hook's locations will be computed in one second intervals during the lifting operation.

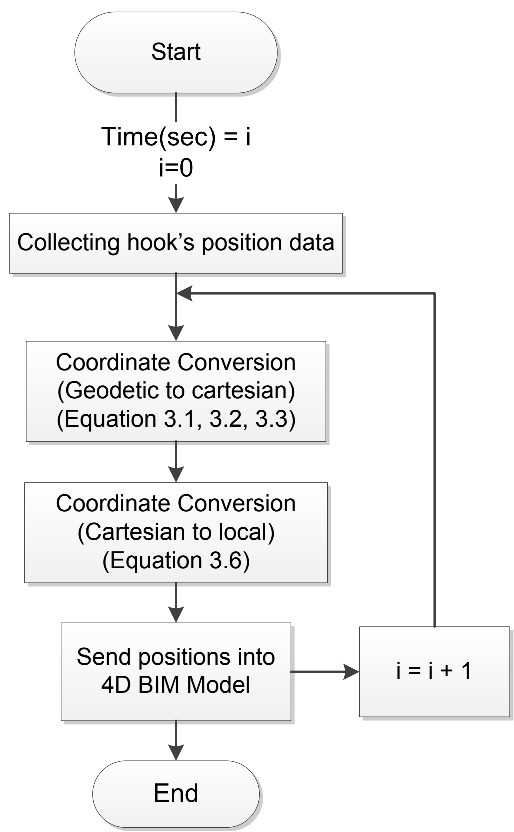


Figure 3-7: The Lifted Load Location Acquisition Flowchart

Since the geodetic (ellipsoidal) coordinate is used in GPS calculation, the outputs need to be converted into local coordinates in two steps. In geodetic coordinates each individual point is expressed with latitude (Φ), longitude (λ) and elevation (h) compare to ellipsoid surface. In following equations, North latitudes and East longitudes are considered as positive value and conversely, South latitudes and West longitudes are negative (Ogaja 2011).

$$X = (N + h) \cos \Phi \cos \lambda \tag{3.1}$$

$$Y = (N + h) \cos \Phi \sin \lambda \tag{3.2}$$

$$Z = [N (1-e^2) + h] \sin \Phi \tag{3.3}$$

$$N = \frac{a}{\sqrt{1 - e^2 \sin^2 \Phi}} \text{ (radius of curvature in the prime vertical)} \tag{3.4}$$

The World Geodetic System 1984 (WGS84) is used as a reference for satellite coordinates (Ogaja 2011). The WGS84 datum surface is a symmetric ellipsoid that formed with semi major axis (a = 6378138m) and flattening (f = 1/298257). The term e, as an eccentricity is defined as following equation (3.5).

$$e^2 = 2f - f^2 \tag{3.5}$$

Finally, the coordinate conversion from Cartesian coordinate (x, y, z) to local coordinate (e, n, u) is implemented via the following matrix (3.6).

$$\begin{bmatrix} e \\ n \\ u \end{bmatrix} = \begin{bmatrix} -\sin \Phi & \cos \Phi & 0 \\ -\cos \Phi \sin \lambda & -\cos \Phi \sin \lambda & \cos \lambda \\ \cos \Phi \cos \lambda & \cos \Phi \cos \lambda & \sin \lambda \end{bmatrix} \begin{bmatrix} X \\ Y \\ Z \end{bmatrix} \tag{3.6}$$

Based on the identified position, the load’s bounding box is illustrated within the 4D BIM model in real time. These continuous events within the 4D BIM model will be used in the proposed algorithm for detecting the possible dangerous situations during tower crane operations.

3.2.5 Proactive Safety Model

After previous sections discussed the schematic flowchart of the proposed model and its sub modules, this part describes the detailed interaction and sequence of the safety check algorithm according to explained module and sub-modules. In order to develop the safety check procedure, the integrated Revit BIM platform is used to accelerate the time of process while transferring BIM model into the simulator software such as Navisworks software needs much time. Hence, the conflict detection is developed through Revit API.

In this process the tower crane's load bounding box and related location is considered as a target object. On contrast, the pre-defined workspaces for equipment, workers and building components are reflected as restricted area. In proposed safety check algorithm in Figure 3-8, existing information regarding to generated boxes from the preceding part are utilized as an input of the algorithm. Since the load's location is time dependent while tower crane is in operation, updating rate of one second is assigned for retrieving processes. Then, by retrieving hook location through added plug-in within Revit model, corresponded bounding box generates into the model and overlap detection is checked in near real time.

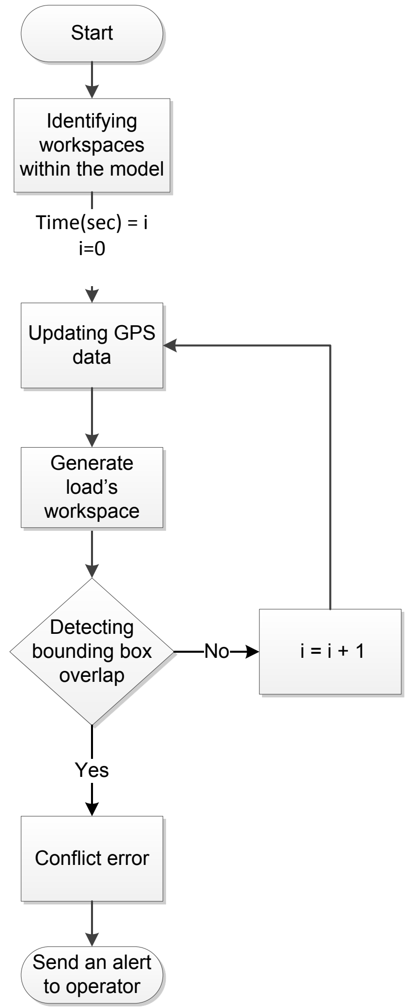


Figure 3-8: Conflict detection algorithm

In the following picture, two scenarios are depicted to visualize how model works (Figure 3-9). The green cylindrical box and blue rectangular boxes illustrate the load and workspaces respectively. Since these boxes are generated based on consideration of safety clearances, the model will trigger the message to the operator once the clash happens between green and blue boxes

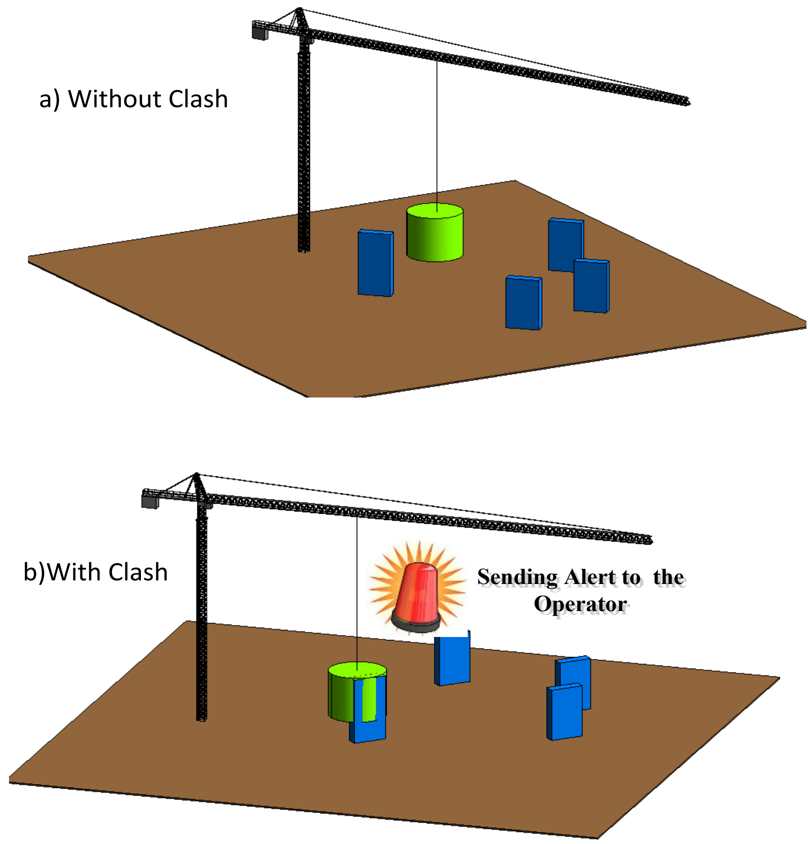


Figure 3-9: Conceptual scenario for proposed model

3.3 Summary

This chapter presented a novel tower crane safety system which uses the BIM model as a main module and four sub modules. GPS technology is used for tracking the tower crane's load in real time.

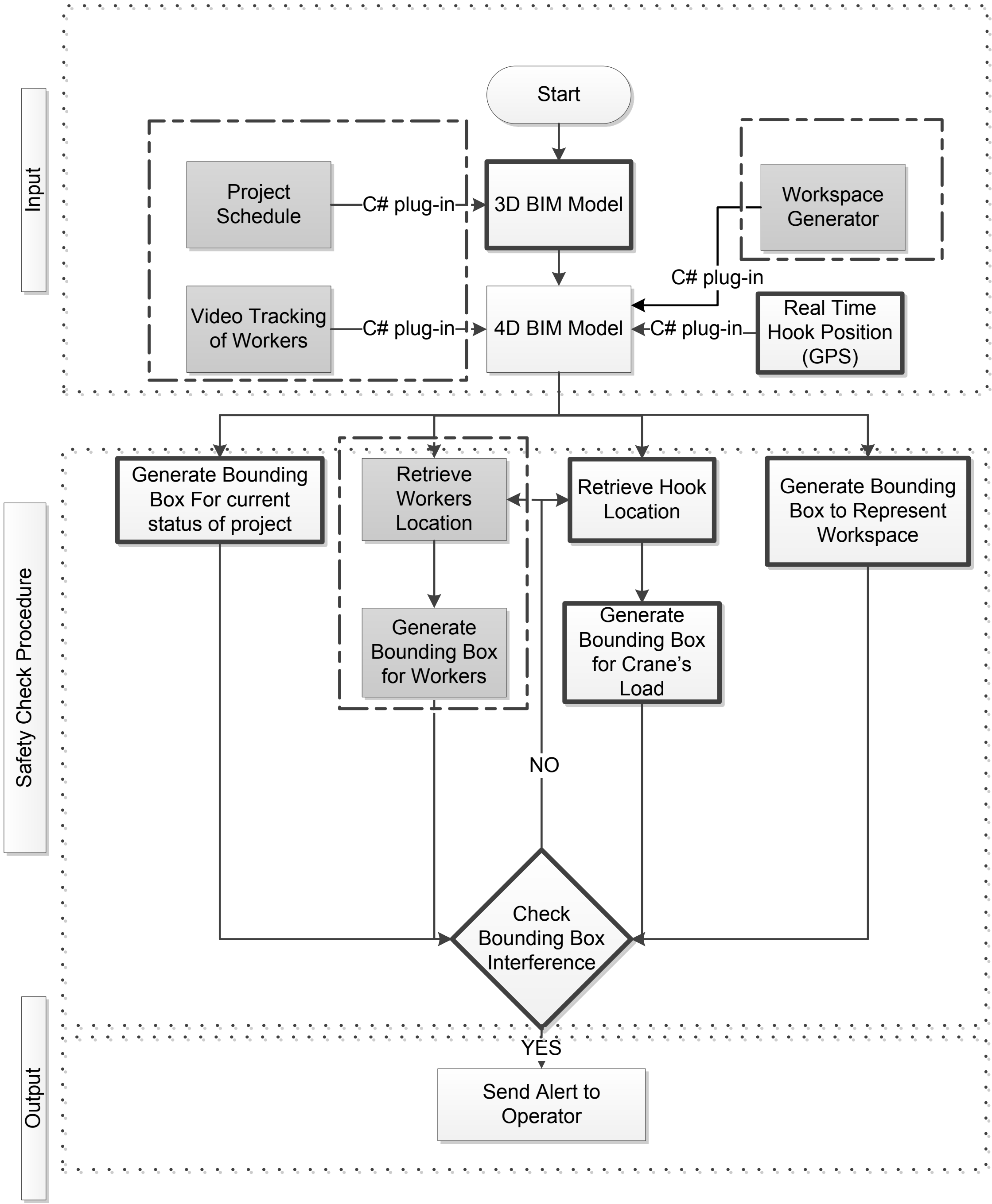


Figure 3-10: Detailed flowchart of proposed model

In Figure 3-10, the detailed flowchart of proposed model is depicted in three divisions of input, safety check procedure and output.

In first tier of the flowchart, the dashed bolded boxes corresponding to schedule and 3D video tracking have not developed and integrated in this study and recommended as future works. It should be mentioned that workspace allocation dotted bolded box which is developed by Wu and Chiu (2010), is integrated in BIM model through adding the coded plug-in in C# language. 3D BIM model and hook positon tracker in bolded boxes are developed and integrated in Revit model to support model for near real time processing.

In the second tier, the written codes in C# language retrieves hook location constantly and convert the acquired coordination to local coordination (Figure 3-7). In order to generate workspace for workers, equipment and project components and also load's bounding box in BIM model, the drawing features in Revit API are manipulated and programmed in C# to be useable for user in an easy way. In order to detect conflict among interested entities, the corresponding geometry for each entity are extracted from model and then clash detection is conducted based on Figure 3-8. The dashed bolded box in this tier is neither developed nor integrated in this study.

The developed model used BIM model features and 3D tracking technology to be free of tags and sensors which make model more feasible in terms of cost savings compares to previous models. Implementing the safety checks within the same environment which BIM model was created will prevent the time-consuming file transferring procedure.

Chapter 4: Model Implementation and Validation

4.1 General

In this chapter, the implemented tools for workspace allocation and proximity detection system are presented. The related features for each plugin and each designed user interface are described. The chapter ends by explaining the case study analyzed for validating the model and its impact on tower crane daily operation.

4.2 Developed Model

This framework includes one module and four sub modules which should be integrated into the 3D BIM model. Since two out of four sub modules of the proposed methodology have been implemented and developed by previous researchers (Park 2012 and Montaser 2013), the validation process only addresses the two modules that are being presented for the first time.

In order to develop the proposed methodology in Figure 3-10, the 3D BIM model is merged with plugins. In this study, Autodesk Revit 2014 is used as the BIM platform. The Revit .NET API allows users to add or use the existing features of BIM model for adding more extensions. As it can be seen in Figure 3-10, 3D BIM model should be updated daily, and after workspaces are generated within the model. The user will define all the required workspaces, and the safety system will use the identified zones as an unauthorized area for tower crane's load. As explained above, developing the code for 3D tracking of workers and integration of time and BIM model have been implemented before. Hence in the following sections, workspace generator, load tracking and safety detection model will be explained.

4.2.1 Workspace Generator

According to the defined objectives of this study, workspaces are used to identify and recognize the occupied areas. Several types of workspaces have been defined but these following types are used in this research due to high compatibility with construction projects: labor, path, material, equipment and building components spaces. The workspace generator plugin is written in C# language with visual studio 2010 using the Revit .NET API (Figure 4-1).

```
        private void SetStartSetting()
        {
            Operation = OperationEnum.ChangeAgent;
            btnStart.Text = !Syncronized.ActiveSyncroniz ? "Start" : "Stop";
        }

        private void MassSetting_Load(object sender, EventArgs e)
        {
            SetStartSetting();
        }

        private void SetTowerCrane()
        {
            Properties = new Dictionary<string, string>();
            if (txtDepth.Enabled)
                Properties.Add("Depth", txtDepth.Text);
            if (txtHeight.Enabled)
                Properties.Add("Height", txtHeight.Text);
            if (txtRadius.Enabled)
                Properties.Add("Radius", txtRadius.Text);
            if (txtWidth.Enabled)
                Properties.Add("Width", txtWidth.Text);
}


        private void SetSetting()
        {
            Properties = new Dictionary<string, string>();
```

Figure 4-1: Workspace generating interface code in C#

This plugin helps the safety management team define the zones of interest as the occupied zone which could include workers, equipment, materials or a combination of more than one. The developed interface for identifying static workspaces is illustrated in Figure 4-2. In the picture below, there are two list boxes: work space type and work space shape.

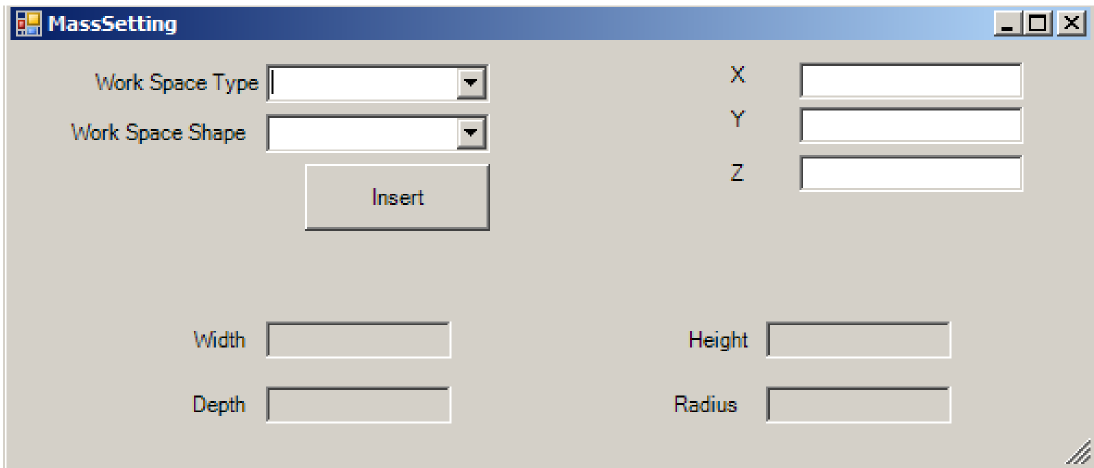


Figure 4-2: Workspace generating interface

The user can select the work space type list box and by scrolling down, the preference type of work space can be selected from a drop-down menu. By choosing one out of five types of workspaces, the chosen type will be assigned to generated elements properties for further usage (Figure 4-3).

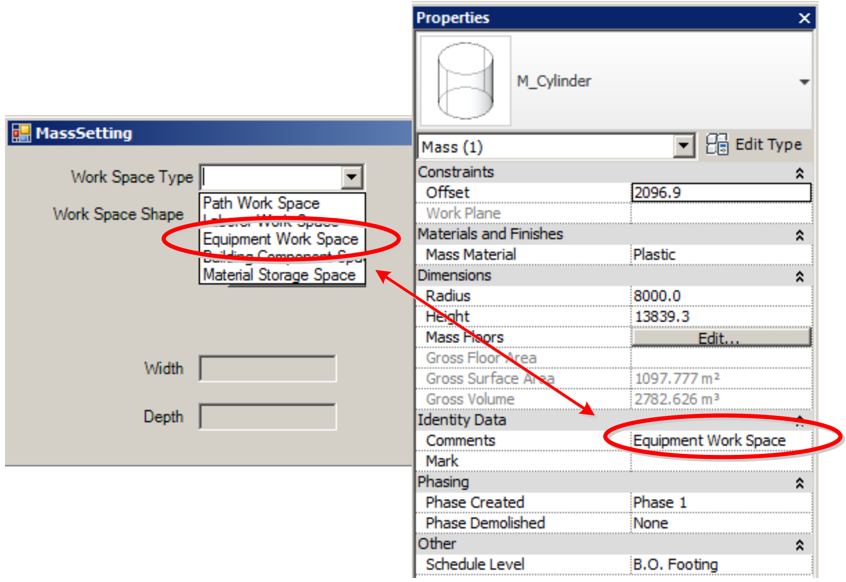


Figure 4-3:How the workspace type stores in element properties

Depending on different materials or equipment, the demand for shape of workspaces could vary. In the shape list box, the user has an access for selecting the shape which is best models the occupied space. This study works under the assumption that the necessary information for workspaces allocation is available, accordingly the user can insert the workspace's position and dimensions easily into the correspond boxes. These features will be adjustable later also, so the user can check the place of workspaces visually in Revit model (Figure 4-4).

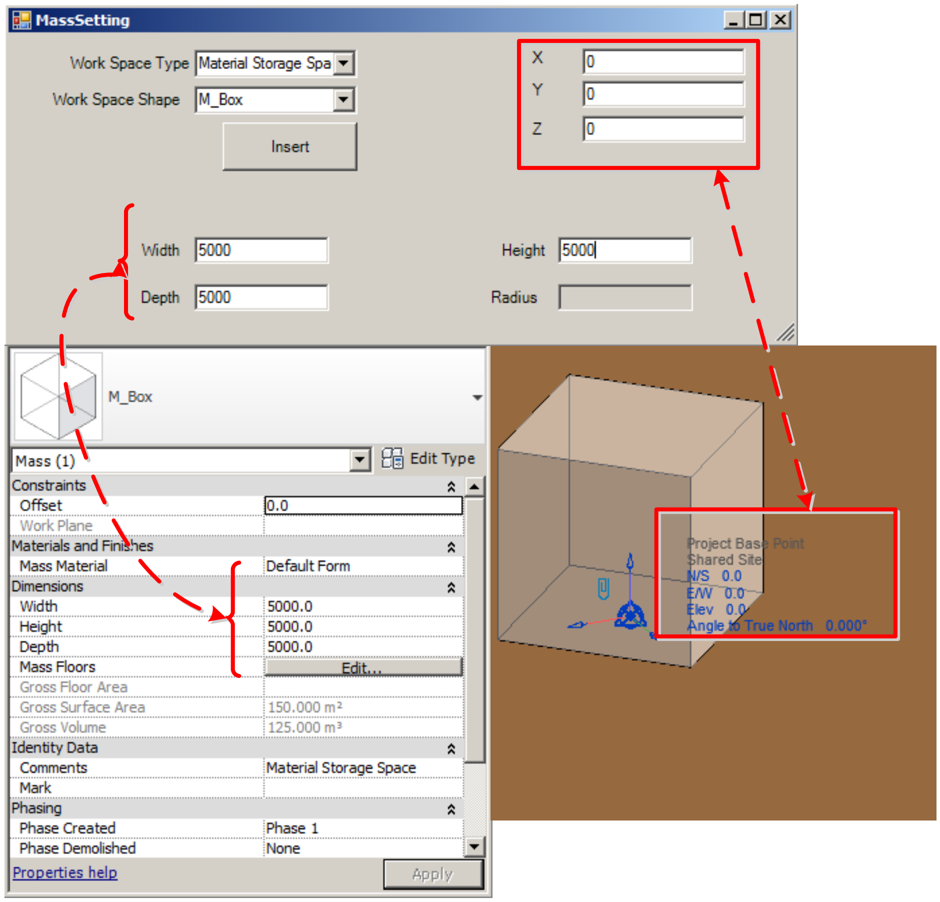


Figure 4-4:Selecting Workspace Characteristic Manually

4.2.2 Proximity Detection

In this research, GPS technology is selected to capture load's location in real time, this selection is mainly due to low initial price and outdoor functionality of the GPS. The time interval of one second is chosen for the GPS device to update information and also storing it into the device database. Since Revit Application is the main module for updating and visualizing the load position in the developed model, the acquired data is transferred into the 4D BIM model. Figure 4-5 depicts the data exchange relation between senders and receivers. In this system GPS/GSM network is utilized for load tracking in real time. The information transfer between GPS segment and mobile service provider can be implemented by adjusting the system configuration, so there is no need to develop the computer programming on the existing communication technologies.

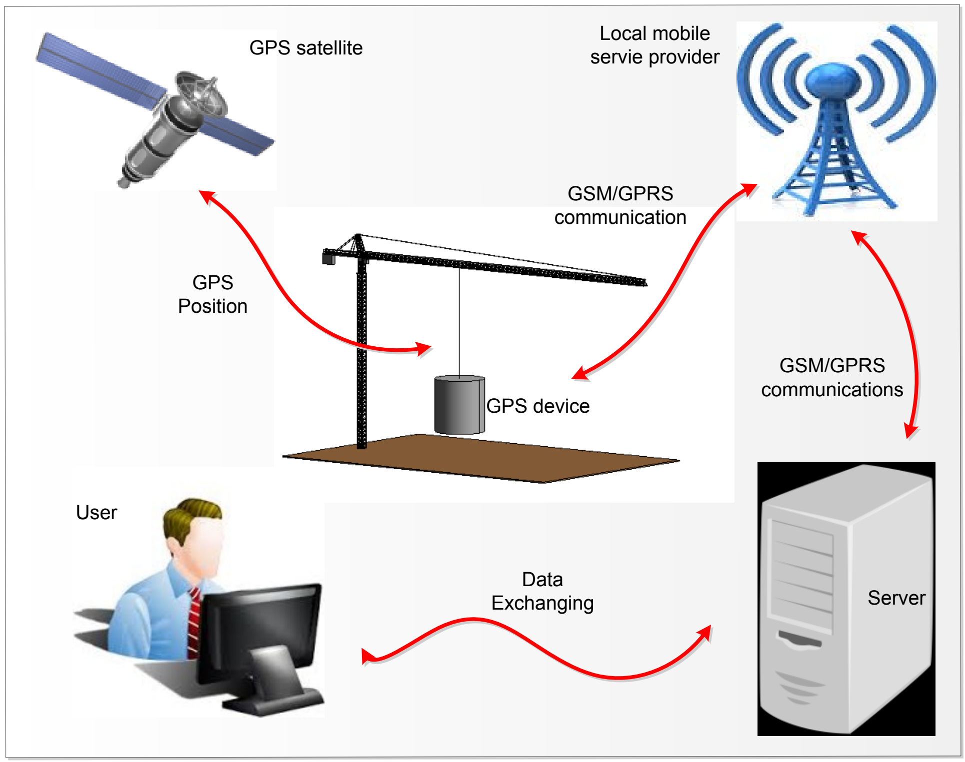
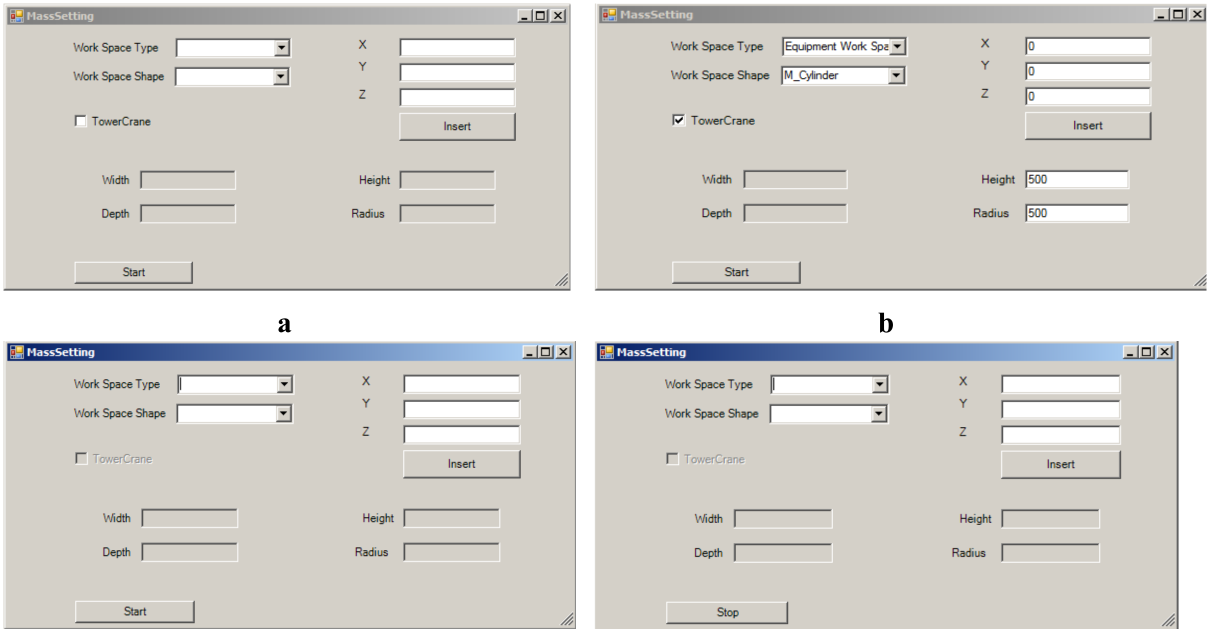


Figure 4-5:The GPS/GSM network for tracking the Tower crane's load

Since the proximity safety system is processed in Revit platform, the acquired data is integrated into the Revit application through computer programming in C# language. Therefore, the Revit plug in is coded in C# language which enable Revit user to read files from data base and localize interested object in BIM model.

In order to make user interface more friendly for the end user, a tower crane check box is provided in the message box (Figure 4-6a). By checking the checkbox the processor realizes that the given information belongs to the load, and consequently the system automatically updates the position from the database (Figure 4-6b). Tower crane checkbox will be inactive after adding all the required information (Figure 4-6c).



a b

c d

Figure 4-6:User Interface for Tower Crane's load tracking

After providing required data as an input for the model, the safety algorithm is developed in C# language as well (Figure 4-7).

```
if (periodTime == DateTime.MinValue)
                periodTime = DateTime.Now;
            // check the current time
            DateTime now = DateTime.Now;
            TimeSpan elapsedTime = now.Subtract(periodTime);
            double second = elapsedTime.Seconds;

            //// write a comment to the journal file for diagnostic purposes
            //uiApp.Application.WriteJournalComment("Idle check. Elapsed time = "
+ minutes, true);

            // don't do anything if less than 3 minutes since last auto-save
            if (second < 1)
                return;

            ActiveSyncroniz = false;
             var conclusion= ExtCmd.Pooling();
            if (conclusion!=null)
            {
                var description = conclusion.get_Parameter("Comments").AsString();
                var location =( conclusion.Location as LocationPoint).Point;
                MessageBox.Show(string.Format("Overlap Error with {0} element in
position ({1},{2},{3})", de }
            ActiveSyncroniz = true;
```

Figure 4-7: Load tracking sample code in C#

By pushing the Start button, the developed code retrieves load's position and the hooked object will be moved in Revit model based on the given information in previous step while hooking operation is in process (Figure 4-6b). The user can stop the retrieving procedure until the further operation gets ready to start (Figure 4-6d). To increase the processing time of safety model, moving load visibility is only considered for starting and ending points and also where that collision takes place.

In the final stage, safety model algorithm checks the moving load bounding box with areas defined as workspaces. Since safety clearance is considered in both load and workspace dimensions, the system can identify and detect dangerous situations before happening. In case of having collision between crane's load and workspaces, a message box pops up on Revit screen which includes the position and type of workspaces (Figure 4-8).

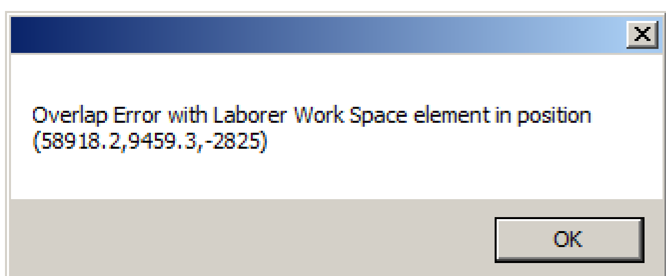


Figure 4-8: Collision detection popup message

4.3 Case Studies

This section will explain two case studies to validate and check the applicability of the developed model on construction projects. As it was mentioned earlier, the implementation and validation of 3D video tracking method and also 4D BIM-based scheduling is out of the scope of this research. Hence, only workspaces allocation, real time tracking and proximity detection are validated in different scenarios.

4.3.1 Case Study 1

In order to validate workspaces assignment procedure, the BIM model of the Center for Structural and Functional Genomics (CSFG) at Concordia University is used in validation process (Figure 4-9). The developed plug in will be deployed in this model to generate and allocate required workspaces regarding to the available information. The required data for workspaces which are shape, position and dimensions can be acquired by different ways that are not within the scope of this research.

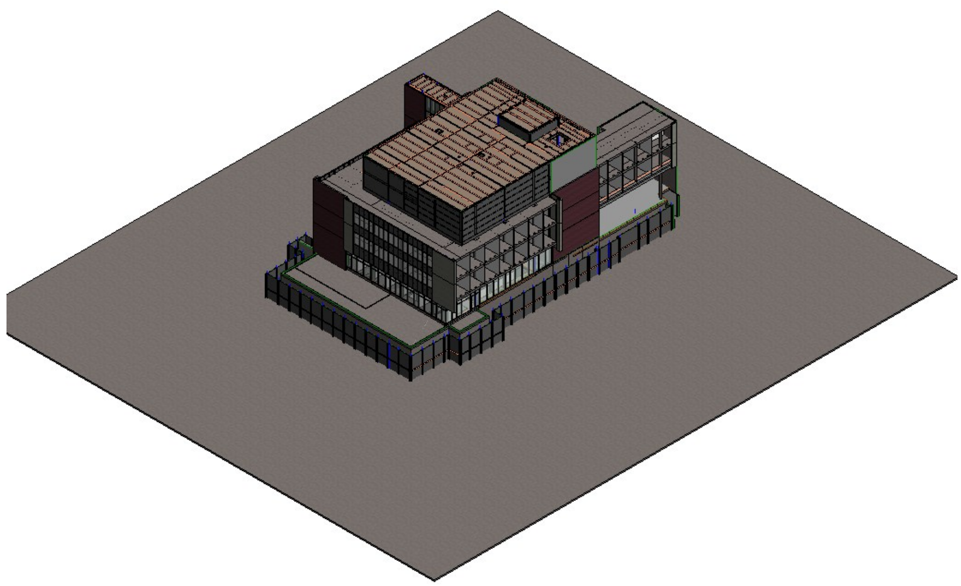


Figure 4-9:Genomic building BIM model

The 4D BIM model does not include the temporary facility and also operating equipment. In order to implement the workspaces assignment procedure, the updated 4D BIM model of the project is utilized to reflect the real status of the project at any specific time. Since types of temporary facilities and construction equipment vary based on project demands, they cannot be inserted in the completed BIM model. Therefore, the workspaces allocation approach is implemented in a daily manner or tower crane-based activity in order to show occupied areas. In the following pictures, existing resources and updated Revit model is depicted to visualize the project status in two different specific days (Figure 4-10 and Figure 4-11). As it can be seen, the number of construction equipment, labors and materials increase as project progresses. In following pictures, type and location of equipment and other resources are gained through existing information.

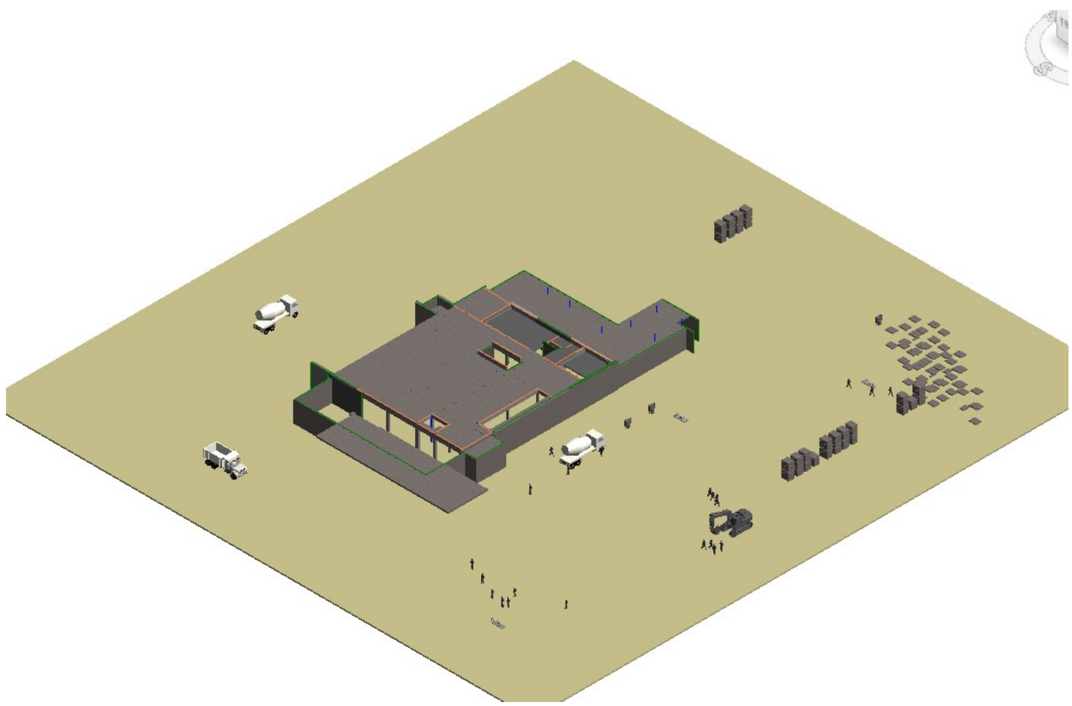


Figure 4-10:Project updated status and existing resources after 4 months

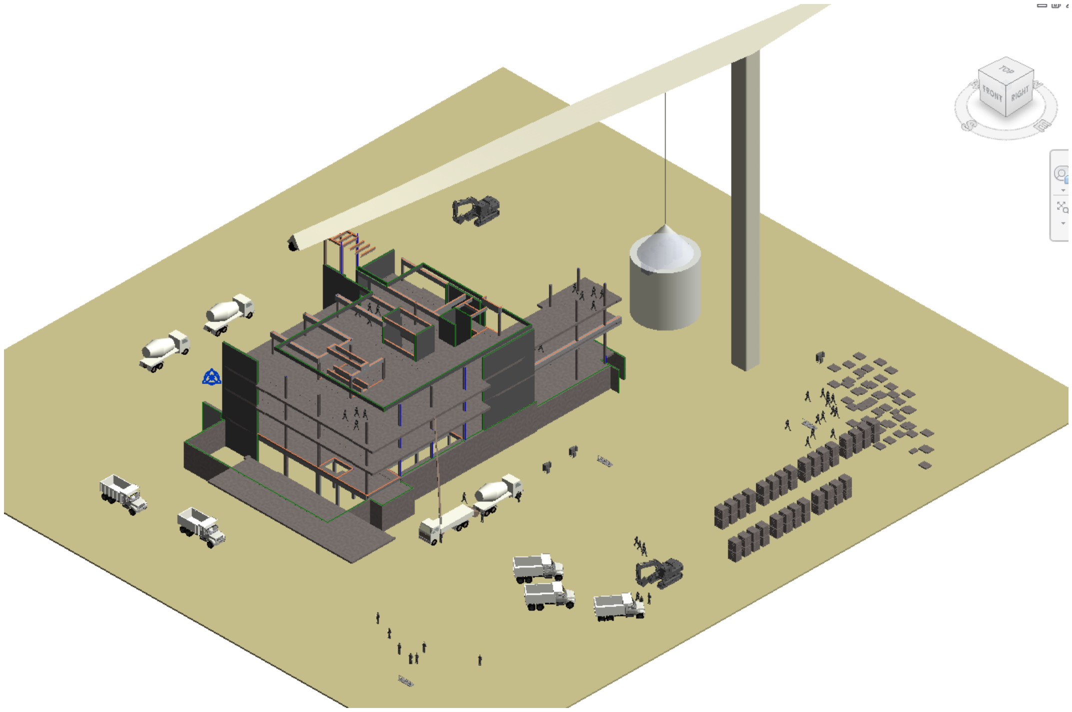


Figure 4-11:Project updated status and existing resources after 6 months

After updating the model, the user can insert available information and workspace types into the plugin interface for allocating the workspaces. These defined workspaces will be used further for implementing the safety algorithm. In Figure 4-12, labor workspace is generated using to the interface inputs.

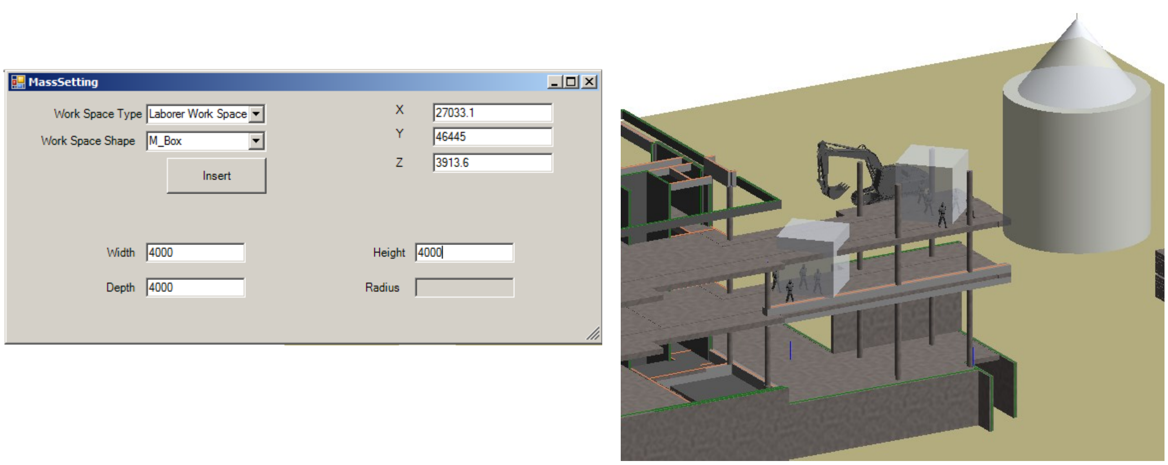


Figure 4-12:Allocated labor workspace based on available information

4.3.2 Case Study 2

The second case study aims to validate tower crane safety model in real time. In this part, the prepared BIM model from previous case study is applied for validating the safety system. Since the process of constructing of this model is already done, the positions of tower crane and attached load are tested based on two scenarios:

1- With collision
2- Without collision

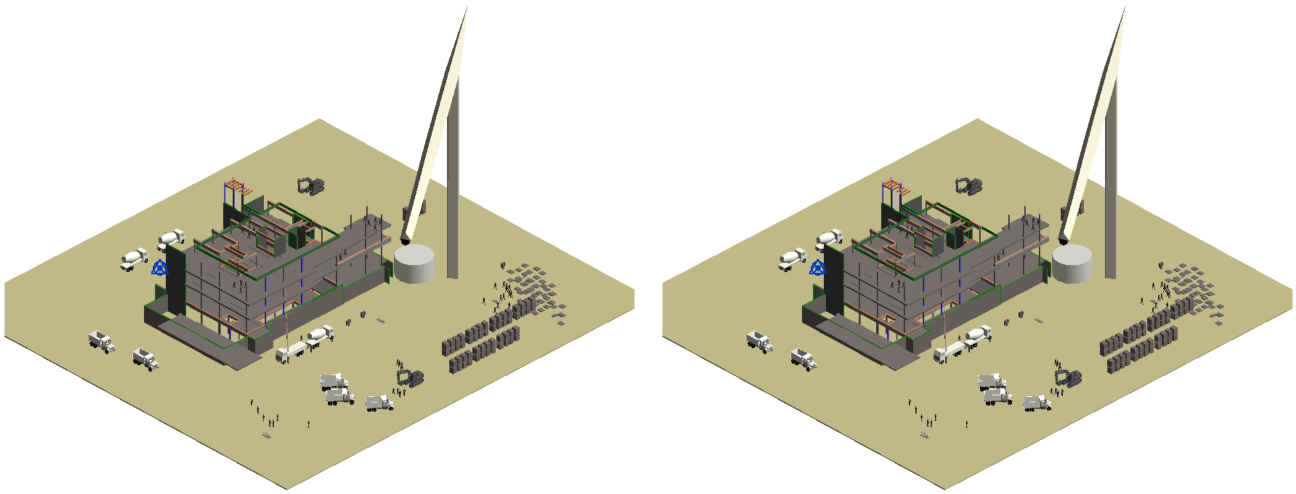
In order to implement these two scenarios, positions of hook and attached load are considered as following table (Table 4-1).

Table 4-1: Load's coordination in local coordinate system

Number	Load's coordination (mm)		
	x	y	z
Start	70918.2	19059.3	-5126
2	69918.2	18259.3	-4926
3	69418.2	17859.3	-4826
4	68918.2	17459.3	-4726
5	68418.2	17059.3	-4626
6	67918.2	16659.3	-4526
7	67418.2	16259.3	-4426
8	66918.2	15859.3	-4326
9	66418.2	15459.3	-4226
10	65918.2	15059.3	-4126
11	65418.2	14659.3	-4026
12	64918.2	14259.3	-3926
13	64418.2	13859.3	-3826
14	63918.2	13459.3	-3726
15	63418.2	13059.3	-3626
16	62918.2	12659.3	-3526
17	62418.2	12259.3	-3426
18	61918.2	11859.3	-3326
19	61418.2	11459.3	-3226
20	60918.2	11059.3	-3126
21	60418.2	10659.3	-3026
22	59918.2	10259.3	-2926
23	59418.2	9859.3	-2826
24	58918.2	9459.3	-2726
25	58418.2	9059.3	-2626
26	57918.2	8659.3	-2724
27	57418.2	8259.3	-2723
28	56918.2	7859.3	-2722
29	-500	-400	-2722
30	55918.2	7059.3	-2720
31	55418.2	6659.3	-2719
32	54918.2	6259.3	-2718
33	54418.2	5859.3	-2717
34	68918.2	17459.3	-4825
35	68418.2	17059.3	-4725
36	67918.2	16659.3	-4625
37	67418.2	16259.3	-4525
38	66918.2	15859.3	-4425
39	66418.2	15459.3	-4325
40	65918.2	15059.3	-4225
41	65418.2	14659.3	-4125
42	64918.2	14259.3	-4025
43	64418.2	13859.3	-3925
44	63918.2	13459.3	-3825
45	63418.2	13059.3	-3725
46	62918.2	12659.3	-3625
47	62418.2	12259.3	-3525
48	61918.2	11859.3	-3425
49	61418.2	11459.3	-3325
50	60918.2	11059.3	-3225
51	60418.2	10659.3	-3125
52	59918.2	10259.3	-3025
53	59418.2	9859.3	-2925
54	58918.2	9459.3	-2825
55	58418.2	9059.3	-2725

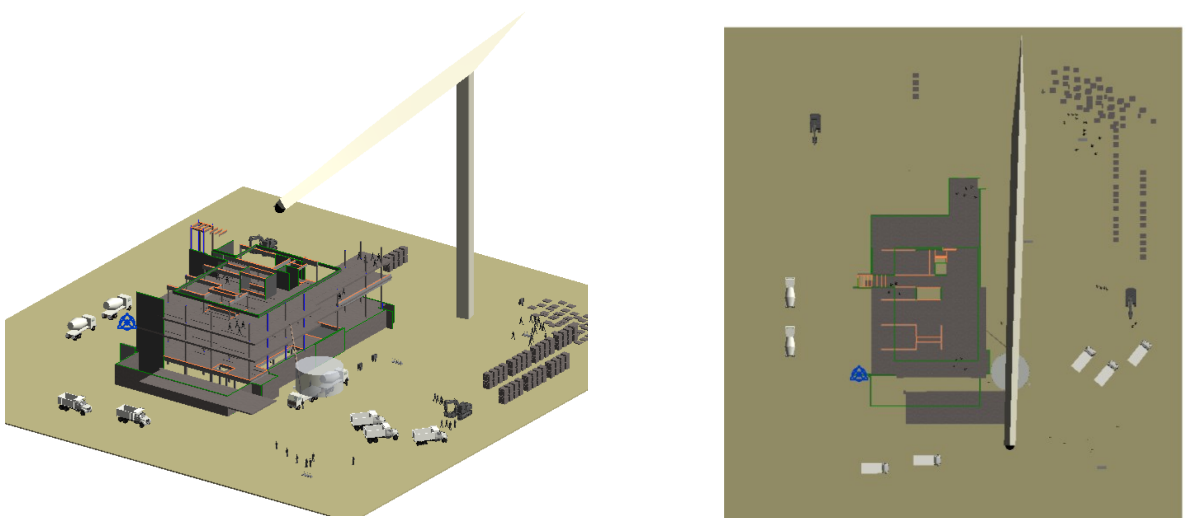
In order to validate the proposed model, the first point of hooking operation is taken from above table which is named start. After that the dimensions of load are inserted arbitrarily. Since in the first scenario, loading and unloading without collision is the goal of the test, all types of workspaces are filtered from Revit model (Figure 4-13).

As can be seen, load is moved from loading to unloading point without receiving any warning message, while the load is completely situated over two machinery equipment.



Side view Top view

a-Start point of loading operation

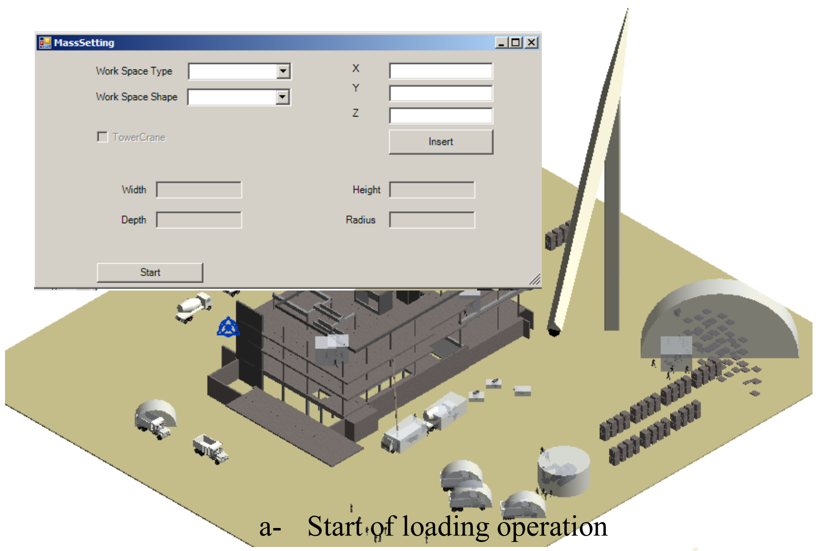


Side view Top view

b-End point of unloading operation

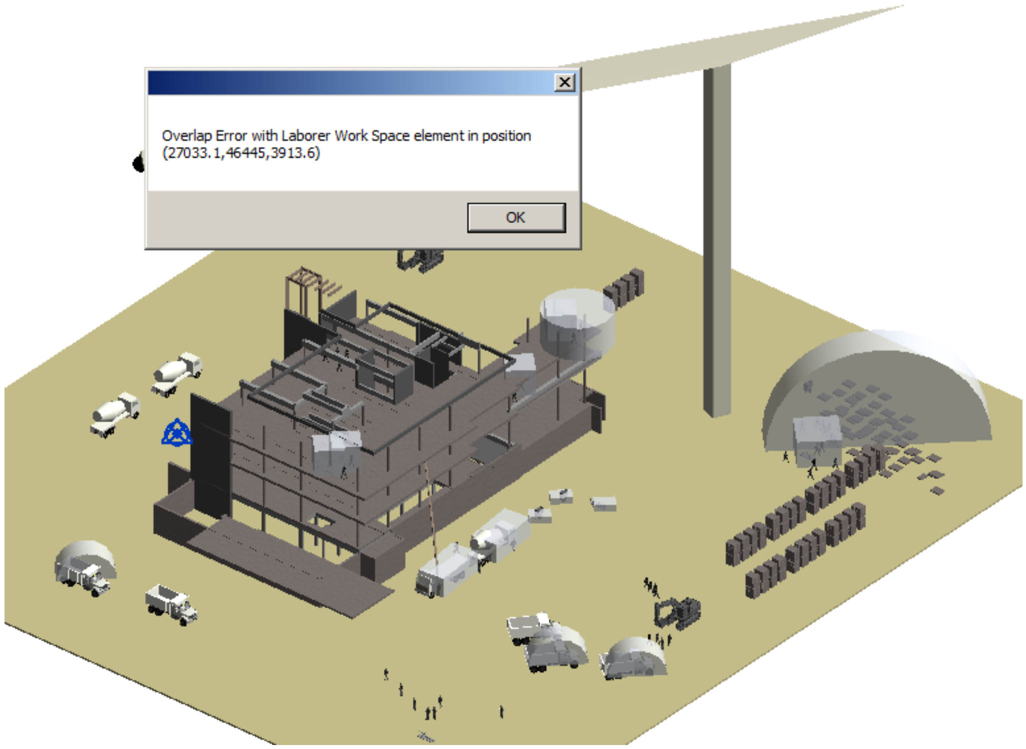
Figure 4-13:Isolated model from workspaces

In second scenario, the defined workspaces are unfiltered from the model and safety test is implemented on the new situation. The model identifies the dangerous situation, regarding the intersection between load's bounding box and defined workspaces. Since these boxes are defined by user, safety margins can be considered in the workspaces or even in the attached load. With the aim of validating the system, the path of load's movement is not changed in this part and workspaces are the only elements which are added into the BIM model.



a- Start of loading operation

b- First collision with defined workspace



c- Second collision with defined workspace

Figure 4-14: How the model sends an error in case of overlapping

In Figure 4-14, the loading operation is depicted in three frames. In frame a, the initial point of the attached load and existing workspaces on construction site are shown. By clicking the start point, the attached load starts moving within the BIM model in real time (Figure 4-14a). The safety system retrieves the load location in defined intervals, until the intersection with one of the defined workspaces took place (Figure 4-14b). At the moment of conflict, the dialog box will appear on the screen and shows the corresponding coordination of contact and also type of the workspace which is struck by the load. In order to test the developed method for another time, the intersected workspace in previous test is removed and the model is run for the second round. It can be seen in Figure 4-14c, that the load is struck to defined workspace in another location of construction site where several workers are involved in activity.

4.4 Summary

In this chapter, the developed model for improving the safety of tower crane operation is explained in detail. First, the developed plugin for generating the workspaces within the Revit model are described. Then, the user inserts required information includes type, shape, dimensions and position of workspaces which are assumed as available information for this study. Second, the tower crane feature was added to the interface in order to define and localize the tower crane's load. By inserting the tower crane's load into the model, this feature will be inactive, since the model was designed for one tower crane. The user can start the safety check algorithm by pushing the start button and if any collision will take place in the model, the message box will appear on the screen including the type of workspace and position of intersection information.

Chapter 5: Conclusions and Future Works

5.1 Conclusions

The rugged, rough and dynamic work environment in the construction industry contributes to high number of work-related injuries and accidents compared with the other industries. Published statistics and reported studies indicate that most common causes of fatal occupational injuries in construction projects are attributed to contact with object or equipment, transportation incidents and falls. Human errors caused by many outer factors (fatigue, repetitive tasks, feeling confident, etc.) can lead to these accidents. To increase workers' awareness and also improve project safety conditions, this study presents a new approach to monitor the tower crane's daily operation to prevent unpleasant accidents between the crane's load and the construction entities. The proposed model integrates the schedule and 3D BIM model to produce a 4D BIM model. The 4D BIM model allows visualizing the up to date project status within the BIM model. The prepared 4D BIM model includes all constructed building elements and existing facilities for construction operations. In order to develop tower crane safety system, GPS technology is used for tracking tower crane's load and then the captured location is sent into the Revit model for retrieving load position in the model. In this system the required workspaces for materials, equipment and workers are modeled in Revit BIM model to reflect dangerous areas and also occupied zones by workers. To support this system, the 3D video tracking system developed by Park et al. (2012), can be used to track workers when they leave pre-defined workspaces. In the safety check algorithm, the crane' load generated box in Revit model will be compared with defined workspaces to identify probable collisions. In case of intersection among bounding boxes, the message box will appear on the screen which can be used to trigger further actions.

5.2 Research Contribution

The proposed safety system is implemented through the integration of minimum number of tracking technologies and BIM model to detect and identify obstructive, occupied and dangerous areas during the tower crane operation. The related contribution to this research can be mentioned as follow:

- The corresponding cost for developed model is significantly less than the previous studies which use tracking technology for detecting and identifying of project entities.
- Using least number of tracking technologies for developing safety detection system.
- Implementing the safety check system for tower crane in faster near real time.
- Providing a safety system where workers are not obliged to be equipped by sensors or tags, i.e. tag free.
- The developed model accounts for temporary support equipment onsite and models them as obstruction constraints.
- Utilization of BIM model features to generate updated 4D BIM that capture the progress of constructed building elements.
- Supports accurate estimate proximity detection system for safety purposes.

5.3 Limitations and Recommendations for Future Work

This section deals with existing limitation of this research which can be improved in future works to enhance the developed tower crane safety system. The main limitations can be summarized as follows:

- In construction projects workspaces required dimensions for equipment and different facilities can vary during the daily activity. For example excavator workspace shape will change frequently, since its moving mechanism is complex. In this study, the model generates static workspaces which do not change by the time or types of motion.
- Workspace position and its dimension should be calculated based on available resources, gang size of each activity and required clearance distance from other ongoing activities which are assumed as an available data for this study.
- 3D video tracking technology is proposed in tower crane safety framework to support workers who leave the workspaces either intentionally or unintentionally. The development and integration of this technology is recommended for future studies.
- Error analyses for GPS technology compared to other technologies are not implemented.
- Most of construction sites may use more than one tower crane at the same time. Therefore adding more options into the model for considering several numbers of tower cranes can be helpful.

References

Akinci, B., Fischer, M., & Kunz, J. (2002). “Automated generation of work spaces required by construction activities.” *Journal of Construction Engineering and Management, 128*(4), 306-315.

Al-Hussein, M., Alkass, S., & Moselhi, O. (2000). “D-CRANE: A database system for utilization of cranes.” *Canadian Journal of Civil Engineering, 27*(6), 1130-1138.

Al-Hussein, M., Alkass, S., & Moselhi, O. (2005). “Optimization algorithm for selection and on site location of mobile cranes.” *Journal of Construction Engineering and Management*, 131(5), 579-590.

Bauer, J., Sunderhauf, N., & Protzel, P. (2007). “Comparing several implementations of two recently published feature detectors.” *Proc. of the International Conference on Intelligent and Autonomous Systems, 6*(pt 1)

Bay, H., Tuytelaars, T., & Van Gool, L. (2006). “Surf: Speeded up robust features. *Computer Vision–ECCV.”* Springer, 404-417.

Beavers, J., Moore, J., Rinehart, R., & Schriver, W. (2006). “Crane-related fatalities in the construction industry.” *Journal of Construction Engineering and Management, 132*(9), 901-910.

Belhumeur, P. N., Hespanha, J. P., & Kriegman, D. (1997). “Eigenfaces vs. fisherfaces: Recognition using class specific linear projection.” *Pattern Analysis and Machine Intelligence, IEEE Transactions on, 19*(7), 711-720.

Bohn, J. S., & Teizer, J. (2009). “Benefits and barriers of monitoring construction activities using hi-resolution automated cameras.” *Proc., of 2009 Construction Research Congress, 1* 21-30.

Bouguet, J. (2004). “Camera calibration toolbox for matlab.” <http://www.vision.caltech.edu/bouguetj/calib doc/index.html>

Cable, L. (2010). “Construction equipment monitoring system.” *Government Product News Penton Media* <Http://govpro.com/products/fleets/management/construction-Equipment-Monitoring-201012/)>

Caldas, C. H., Torrent, D. G., & Haas, C. T. (2004). “Integration of automated data collection technologies for real time field materials management.” *Proceedings of* *the 21st International Symposium on Automation and Robotics in Construction, Jeju, Korea,*

Caldas, C. H., Torrent, D. G., & Haas, C. T. (2006). "Using global positioning system to improve materials-locating processes on industrial projects." *Journal of Construction Engineering and Management, 132*(7), 741-749.

Chae, S., & Kano, N. (2007). "Application of location information by stereo camera images to project progress monitoring." *Proceedings of the 24th International Symposium on Automation and Robotics in Construction, Kochi, Kerala, India,* 19-21.

Chae, S., & Yoshida, T. (2010). "Application of RFID technology to prevention of collision accident with heavy equipment." *Automation in Construction, 19*(3), 368-374.

Challa, S. (2011). "Fundamentals of object tracking." Cambridge University Press.

Chavada, R., Dawood, N., & Kassem, M. (2012). "Construction workspace management: The development and application of a novel nD planning approach and tool."*Information Technology in Construction,* 17, 213-236.

Chen, S., Griffis, F., Chen, P., & Chang, L. (2013). "A framework for an automated and integrated project scheduling and management system." *Automation in Construction, 35*, 89-110.

Cheng, M.-Y., Chen, J.-C. (2002). "Integrating barcode and GIS for monitoring construction progress." *Automation in Construction*, 11 (1), 23-33.

Cheng, T., & Teizer, J. (2013). "Real time resource location data collection and visualization technology for construction safety and activity monitoring applications." *Automation in Construction, 34*, 3-15.

Cheng, T., Venugopal, M., Teizer, J., & Vela, P. (2011). "Performance evaluation of ultra wideband technology for construction resource location tracking in harsh environments." *Automation in Construction, 20*(8), 1173-1184.

Chi, S., & Caldas, C. H. (2011). "Image-based safety assessment: Automated spatial safety risk identification of earthmoving and surface mining activities." *Journal of Construction Engineering and Management, 138*(3), 341-351.

Chua, D. K., Yeoh, K., & Song, Y. (2010). “Quantification of spatial temporal congestion in four-dimensional computer-aided design.” *Journal of Construction Engineering and Management, 136*(6), 641-649.

CommonPoint, Common Point Inc. Common Point Inc., Mountain View, CA, (2007). <http://www.commonpointinc.com/>.

Dalal, N., & Triggs, B. (2005). “Histograms of oriented gradients for human detection. *Computer Vision and Pattern Recognition.” IEEE Computer Society Conference on, 1,* 886-893.

Dawood, N., & Mallasi, Z. (2006). “Construction workspace planning: Assignment and analysis utilizing 4D visualization technologies.” *Computer-Aided Civil and Infrastructure Engineering, 21*(7), 498-513.

Dawood, N., Scott, D., Sriprasert, E., & Mallasi, Z. (2005). “The virtual construction site (VIRCON) tools: An industrial evaluation.” *Journal of Information Technology in Construction*, 10, 43–54.

Eastman, C., Teicholz, P., Sacks, R., and Liston, K. (2008). BIM Handbook: A Guide to Building Information Modeling for owners, managers, designers, engineers and contractors. *John Wiley & Sons, Inc*

Eecke, R. (2010). “Greening (and saving) with GPS fleet tracking.” *Construction News Tracker*<,http://www.forconstructionpros.com/article/10288916/greening-and-saving-with-gps-fleet-tracking>

Engineering News-Record (2008) “Behind a murky name lurks an amazing little tag.” *TheMcGraw-Hill Companies*<http://enr.construction.com/opinions/editorials/archives/080423.asp>

Ergen, E., Akinci, B., East, B., & Kirby, J. (2007). “Tracking components and maintenance history within a facility utilizing radio frequency identification technology.” *Journal of Computing in Civil Engineering, 21*(1), 11-20.

Everett, J. G., & Slocum, A. H. (1993). “CRANIUM: Device for improving crane productivity and safety.” *Journal of Construction Engineering and Management, 119*(1), 23-39.

Fu, C., Aouad, G., Lee, A., Mashall-Ponting, A., & Wu, S. (2006). “IFC model viewer to support nD model application.” *Automation in Construction, 15*(2), 178-185.

Fullerton, C. E., Allread, B. S., & Teizer, J. (2009). “Pro-active-real time personnel warning system.” *Proceedings of the Construction Research Congress, Seattle, Washington,* 31-40.

Ghavami, M., Michael, L. B., & Kohno, R. (2004). “*Front matter* Wiley Online Library.”

Golparvar-Fard, M., Peña-Mora, F., & Savarese, S. (2009). “D4AR–a 4-dimensional augmented reality model for automating construction progress monitoring data collection, processing and communication.” *Journal of Information Technology in Construction, 14*, 129-153.

Gomez, K. (2007). “Cost-effective anti-collision.” *Construction Contractor*, 32.

Gong, J., & Caldas, C. H. (2008). “Data processing for real time construction site spatial modeling.” *Automation in Construction, 17*(5), 526-535.

Guo, S. (2002). “Identification and resolution of work space conflicts in building construction.” *Journal of Construction Engineering and Management, 128*(4), 287-295.

Haas, C., & Lin, K. (1995). “An interactive database system with graphical linkage for computer aided critical lift planning.” *Proceedings of the 12th International Symposium on Automation and Robotics in Construction (ISRC), Warsaw, Poland,* 313-324.

Hammad, A., Wang, H., Zhang, C., Al-Hussein, M, and Cardinal, G. (2007). “Equipment workspace analysis in infrastructure projects.” *Canadian Journal of Civil Engineering*, 34(10), 1247-1256.

Hasan, S., Zaman, H., Han, S., Al-Hussein, M., and Su, Y. (2012). “Integrated Building Information Model to Identify Possible Crane Instability Caused by Strong Winds.” Construction Research Congress 1281-1290.

Hartley, R. I. (1997). “In defense of the eight-point algorithm.” *Pattern Analysis and Machine Intelligence, IEEE Transactions on, 19*(6), 580-593.

Heikkila, J., & Silvén, O. (1997). “A four-step camera calibration procedure with implicit image correction.” *Computer Vision and Pattern Recognition, 1997. Proceedings., 1997 IEEE Computer Society Conference on,* 1106-1112.

Hinze, J., & Gambatese, J. A. (1996). “Addressing construction worker safety in project design.” *Bureau of Engineering Research, University of Texas at Austin*.

Isard, M., & Blake, A. (1998). “Condensation—conditional density propagation for visual tracking.” *International Journal of Computer Vision, 29*(1), 5-28.

Kang, S., & Miranda, E. (2004). “Physics based model for simulating the dynamics of tower cranes.” *International Conference on Computing in Civil and Building Engineering, ICCCBE, Weimar, Bauhaus-University, Germany, 10* 248-253.

Kawata, M. (2007). "Safety Use of Cranes in the Construction Industry." H. K. S. A. R. Occupational Safety and Health Council, ed.

Kim, C., Haas, C. T., Liapi, K. A., & Caldas, C. H. (2006). “Human-assisted obstacle avoidance system using 3D workspace modeling for construction equipment operation.” *Journal of Computing in Civil Engineering, 20*(3), 177-186.

Ko, C. (2010). “RFID 3D location sensing algorithms.” *Automation in Construction, 19*(5), 588-595.

Krygiel, E., & Nies, B. (2008). “Green BIM: Successful Sustainable Design with Building Information Modeling.” *Wiley Publishing, Indianapolis.*

Kwon, S., Bosche, F., Kim, C., Haas, C. T., & Liapi, K. A. (2004). “Fitting range data to primitives for rapid local 3D modeling using sparse range point clouds.” *Automation in Construction, 13*(1), 67-81.

Lee, G., Cho, J., Ham, S., Lee, T., Lee, G., Yun, S., & Yang, H. (2012). “A BIM-and sensor-based tower crane navigation system for blind lifts.” *Automation in Construction, 26*, 1-10.

Lee, J., Park, S., Oh, S., & Kim, Y. (2002). “A study on the work efficiency improvement of tower crane operation using GPS and machine vision.” *Journal of Architectural Institute of Korea, 18*(11), 133-140.

Lee, U., Kang, K., Kim, G., & Cho, H. (2006). “Improving tower crane productivity using wireless technology.” *Computer-Aided Civil and Infrastructure Engineering, 21*(8), 594-604.

Lei, Z., Taghaddos, H., Hermann, U., & Al-Hussein, M. (2013). “A methodology for mobile crane lift path checking in heavy industrial projects.” *Automation in Construction, 31*, 41-53.

Li, H., Chan, G., & Skitmore, M. (2013). “Integrating real time positioning systems to improve blind lifting and loading crane operations.” *Construction Management and Economics, 31*(6), 596-605.

Li, L., Huang, W., Gu, I. Y., & Tian, Q. (2002). “Foreground object detection in changing background based on color co-occurrence statistics.” *Applications of Computer Vision, 2002.(WACV 2002). Proceedings. Sixth IEEE Workshop on,* 269-274.

Lienhart, R., & Maydt, J. (2002). “An extended set of haar-like features for rapid object detection*.” 2002 International Conference on Image Processing, 1,* 900- 903.

Lowe, D. G. (2004). “Distinctive image features from scale-invariant key points.” *International Journal of Computer Vision, 60*(2), 91-110.

Lu, W., Okuma, K., & Little, J. J. (2009). “Tracking and recognizing actions of multiple hockey players using the boosted particle filter.” *Image and Vision Computing, 27*(1), 189-205.

Lucas, B. D., & Kanade, T. (1981). “An iterative image registration technique with an application to stereo vision.” *Ijca, , 81* 674-679.

Luo, X. (2013). “Requirements, specifications and deployment models for autonomous jobsite safety proximity monitoring.” Ph.D. thesis, University of Texas at Austin, Austin, TX.

Luo, X., Leite, F., & O'Brien, W. J. (2011). “Requirements for autonomous crane safety monitoring.” *ASCE International Workshop on Computing in Civil Engineering Miami, Florida,* 331-338.

MacCollum, D. V. (1993). “Crane hazards and their prevention.*” American Society of Safety Engineers Des Plaines*, Ill.

Marfil, R., Molina-Tanco, L., Rodríguez, J. A., & Sandoval, F. (2007). “Real time object tracking using bounded irregular pyramids.” *Pattern Recognition Letters, 28*(9), 985-1001.

Marks, E., & Teizer, J. (2013). “Proximity sensing and warning technology for heavy construction equipment operation.” *Construction Management and Economics*, 31(6), 636-646.

McCuen, T. L. (2009). "The quantification process and standards for BIM." *AACE International Transactions, Association for the Advancement of Cost Engineering*, Seattle, WA, 11.

McFarlane, N. J., & Schofield, C. P. (1995). "Segmentation and tracking of piglets in images." *Machine Vision and Applications, 8*(3), 187-193.

Moon, H., Kang, L., Dawood, N., Ji, S., & Kwan, S. (2009). "Configuration method of health and safety rule for improving productivity in construction space by multi-dimension CAD system." *Iccem/iccpm,*

Moselhi, O., & Alshibani, A. (2007). "Crew optimization in planning and control of earthmoving operations using spatial technologies." *Journal of Information Technology in Construction, 12*, 121-137.

Motamedi, A., & Hammad, A. (2009). "Lifecycle management of facilities components using radio frequency identification and building information model." *Journal of Information Technology in Construction*, 14, 238–262.

Muthukrishnan, K., & Hazas, M. (2009). "Position estimation from UWB pseudorange and angle-of-arrival: A comparison of non-linear regression and kalman filtering." *Location and context awareness*, 222-239

Neitzel, R. L., Seixas, N. S., & Ren, K. K. (2001). "A review of crane safety in the construction industry." *Applied Occupational and Environmental Hygiene, 16*(12), 1106-1117.

Nguyen, H. T., Worring, M., Van Den Boomgaard, R., & Smeulders, A. W. (2002). "Tracking nonparameterized object contours in video." *Image Processing, IEEE Transactions on, 11*(9), 1081-1091.

NIBS. National building information modeling standard, (2013) <http://www.buildingsmartalliance.org/pdfs/mhc_bim_smartmarket.pdf>

Ogaja, C. A. (2011). "Applied GPS for engineers and project managers." ASCE Publications.

Oloufa, A. A., Ikeda, M., & Oda, H. (2003). "Situational awareness of construction equipment using GPS, wireless and web technologies." *Automation in Construction, 12*(6), 737-748.

Park, M. (2012). "Automated 3D vision-based tracking of construction entities." *School of Civil and Environmental Engineering*, *Georgia Institute of Technology*, *Atlanta*, *USA*. Ph.D. thesis,

Park, M., Koch, C., & Brilakis, I. (2011). "Three-dimensional tracking of construction resources using an on-site camera system." *Journal of Computing in Civil Engineering, 26*(4), 541-549.

Peurifoy, R. L., Schexnayder, C. J., and Shapira, A. (2006). "Construction planning, equipment, and methods." 7th Ed., McGraw-Hill, Boston

Riley, D. R., & Sanvido, V. E. (1997). "Space planning method for multistory building construction." *Journal of Construction Engineering and Management, 123*(2), 171-180.

Ross, D. A., Lim, J., Lin, R., & Yang, M. (2008). "Incremental learning for robust visual tracking." *International Journal of Computer Vision, 77*(1-3), 125-141.

Ruff, T. M. (2001). "Monitoring blind spots-A major concern for haul trucks." *E&mj-Engineering and Mining Journal, 202*(12), 17.

Sacks, R., Navon, R., Brodetskaia, I., & Shapira, A. (2005). "Feasibility of automated monitoring of lifting equipment in support of project control." *Journal of Construction Engineering and Management, 131*(5), 604-614.

Schreiber, D. (2008). "Generalizing the Lucas–Kanade algorithm for histogram-based tracking." *Pattern Recognition Letters, 29*(7), 852-861.

Shafique, K. and Shah, M. (2003). "A non-iterative greedy algorithm for multi-framepoint correspondence." *Proceedings of ICCV 2003, IEEE*, Nice, France, 110-115.

Shapira, A., & Lyachin, B. (2009). "Identification and analysis of factors affecting safety on construction sites with tower cranes." *Journal of Construction Engineering and Management, 135*(1), 24-33.

Shapira, A., Rosenfeld, Y., & Mizrahi, I. (2008). "Vision system for tower cranes." *Journal of Construction Engineering and Management, 134*(5), 320-332.

Shapiro, H. I., Shapiro, J. P., & Shapiro, L. K. (2000). "Cranes and derricks" McGraw-Hill New York.

Son, H., & Kim, C. (2010). “3D structural component recognition and modeling method using color and 3D data for construction progress monitoring.” *Automation in Construction, 19*(7), 844-854.

Song, J., Haas, C. T., & Caldas, C. H. (2006). “Tracking the location of materials on construction job sites.” *Journal of Construction Engineering and Management, 132*(9), 911-918.

Stauffer, C., & Grimson, W. E. L. (2000). “Learning patterns of activity using real time tracking.” *Pattern Analysis and Machine Intelligence, IEEE Transactions on, 22*(8), 747-757.

Sugano, H., & Miyamoto, R. (2009). “Parallel implementation of pedestrian tracking using multiple cues on GPGPU.” *Computer Vision Workshops (ICCV Workshops), 2009 IEEE 12th International Conference,* 900-906.

Swain, M. J., & Ballard, D. H. (1991). “Color indexing.” *International Journal of Computer Vision, 7*(1), 11-32.

Synchro, The New Dimension in Construction Project Management, Synchro Ltd, Coventry UK, 2007. www.synchroltd.com/.

Tam, V. W., & Fung, I. W. (2011). “Tower crane safety in the construction industry: A hong kong study.” *Safety Science, 49*(2), 208-215.

Teizer, J., Allread, B. S., Fullerton, C. E., & Hinze, J. (2010). “Autonomous pro-active real time construction worker and equipment operator proximity safety alert system.” *Automation in Construction, 19*(5), 630-640.

Teizer, J., Caldas, C. H., & Haas, C. T. (2007). “Real time three-dimensional occupancy grid modeling for the detection and tracking of construction resources.” *Journal of Construction Engineering and Management, 133*(11), 880-888.

Thabet, W. Y., & Beliveau, Y. J. (1994). “Modeling work space to schedule repetitive floors in multistory buildings.” *Journal of Construction Engineering and Management, 120*(1), 96-116.

Torr, P. H. S. (2002). “Bayesian model estimation and selection for epipolar geometry and generic manifold fitting.” *International Journal of Computer Vision, 50*(1), 35-61.

Tsechpenakis, G., Tsapatsoulis, N., & Kollias, S. (2004). “Probabilistic boundary-based contour tracking with snakes in natural cluttered video sequences.” *International Journal of Image and Graphics, 4*(03), 469-498.

Turk, M., & Pentland, A. (1991). “Eigenfaces for recognition.” *Journal of Cognitive Neuroscience, 3*(1), 71-86.

Viola, P., & Jones, M. (2001). “Rapid object detection using a boosted cascade of simple features.” *Computer Vision and Pattern Recognition, Proceedings of the 2001 IEEE Computer Society Conference on,* 1(1), 511-518.

Wang, H., Zhang, J., Chau, K., & Anson, M. (2004). “4D dynamic management for construction planning and resource utilization.” *Automation in Construction, 13*(5), 575-589.

Wang, L. (2008). “Enhancing construction quality inspection and management using RFID technology.” *Automation in Construction, 17*(4), 467-479.

Workers' Compensation Board-Alberta. (1980). “*Annual report of WCB, the workers' compensation board-Alberta* Workers' Compensation Board-Alberta.” <http://www.engineering.nottingham.ac.uk/icccbe/proceedings/pdf/pf7.pdf >

Wu, I., & Chiu, Y. (2010). “4D workspace conflict detection and analysis system.” *Proceedings of the 10th International Conference on Construction Applications of Virtual Reality,*

Yang, J., Vela, P., Teizer, J., & Shi, Z. (2011). “Vision-based crane tracking for understanding construction activity.” *Proc.ASCE IWCCE,* 258-265.

Yilmaz, A., Javed, O., & Shah, M. (2006). “Object tracking: A survey.” *ACM Computing Surveys (CSUR), 38*(4), 13.

Yoders, J. (2008). “Integrated project delivery using BIM.” *Building Design & Construction, 49*(5), 30-44.

Yokoyama, M., & Poggio, T. (2005). “A contour-based moving object detection and tracking.” *Visual Surveillance and Performance Evaluation of Tracking and Surveillance, 2005. 2nd Joint IEEE International Workshop on,* 271-276.

Zhang, C., & Hammad, A. (2011). “Multiagent approach for real time collision avoidance and path replanning for cranes.” *Journal of Computing in Civil Engineering, 26*(6), 782-794.

Zhang, C., Hammad, A., Soltani, M., Setayeshgar, S., & Motamedi, A. (2012). Dynamic virtual fences for improving workers safety using BIM and RTLS. *14th International Conference on Computing in Civil and Building Engineering,*

Zhang, S., Teizer, J., Lee, J., Eastman, C. M., & Venugopal, M. (2013). "Building information modeling (BIM) and safety: Automatic safety checking of construction models and schedules." *Automation in Construction, 29*, 183-195.

Zhu, Q., Yeh, M., Cheng, K., & Avidan, S. (2006). "Fast human detection using a cascade of histograms of oriented gradients." *Computer Vision and Pattern Recognition, 2006 IEEE Computer Society Conference on, 2,* 1491-1498.

Appendix

1- Developed code for allocation of workspaces

```
using System;
using System.Collections.Generic;
using System.Windows.Forms;

namespace Salar
{
    public partial class MassSetting : Form
    {
        public MassSetting(bool isTowerCrane)
        {
            IsTowerCrane = isTowerCrane;
            InitializeComponent();
            chkTowerCrane.Enabled = !isTowerCrane;
        }

        public double MassLocationX { get; set; }
        public double MassLocationY { get; set; }
        public double MassLocationZ { get; set; }
        public string Description { get; set; }
        public string SelectedMass { get; set; }
        public string MassName {
            get
            {
                return SelectedMass + ".rfa";
            }
        }
        public string MassWitdh { get; set; }
        public string MassDepth { get; set; }
        public string MassHeight { get; set; }
        public string MassRadius { get; set; }
        public bool IsTowerCrane { get; set; }
        public Dictionary<string,string> Properties { get; set; }
        public OperationEnum Operation { get; set; }

        private void btnInsert_Click(object sender, EventArgs e)
        {

            MassLocationX = double.Parse(txtX.Text);
            MassLocationY = double.Parse(txtY.Text);
            MassLocationZ = double.Parse(txtZ.Text);
            IsTowerCrane = chkTowerCrane.Checked;
            SelectedMass = cmbWorkSpaceShape.SelectedItem.ToString();
            Description = cmbWorkSpaceType.SelectedItem.ToString();
            Operation= OperationEnum.AddMass;
            if (IsTowerCrane)
```

```
            {
                SelectedMass = "M_Cylinder";
                SetTowerCrane();
                this.Close();
            }

            SetSetting();

            this.Close();
        }

        private void SetStartSetting()
        {
            Operation = OperationEnum.ChangeAgent;
            btnStart.Text = !Syncronized.ActiveSyncroniz ? "Start" : "Stop";
        }

        private void MassSetting_Load(object sender, EventArgs e)
        {
            SetStartSetting();
        }

        private void SetTowerCrane()
        {
            Properties = new Dictionary<string, string>();
            if (txtDepth.Enabled)
                Properties.Add("Depth", txtDepth.Text);
            if (txtHeight.Enabled)
                Properties.Add("Height", txtHeight.Text);
            if (txtRadius.Enabled)
                Properties.Add("Radius", txtRadius.Text);
            if (txtWidth.Enabled)
                Properties.Add("Width", txtWidth.Text);
        }


        private void SetSetting()
        {
            Properties = new Dictionary<string, string>();
            if(txtDepth.Enabled)
                Properties.Add("Depth", txtDepth.Text);
            if (txtHeight.Enabled)
                Properties.Add("Height", txtHeight.Text);
            if (txtRadius.Enabled)
                Properties.Add("Radius", txtRadius.Text);
            if (txtWidth.Enabled)
                Properties.Add("Width", txtWidth.Text);
        }

        private void cmbWorkSpaceShape_SelectedIndexChanged(object sender,
EventArgs e)
        {
            txtWidth.Enabled = false;
            txtDepth.Enabled = false;
            txtRadius.Enabled = false;
            txtHeight.Enabled = false;
```

```
            string selectedMass =
cmbWorkSpaceShape.SelectedItem.ToString().Replace(" ","").ToLower();
            if (selectedMass == MassType.M_BarrelVault.ToString().ToLower())
            {
                txtWidth.Enabled = true;
                txtDepth.Enabled = true;
            }
            else if (selectedMass == MassType.M_Box.ToString().ToLower())
            {
                txtWidth.Enabled = true;
                txtDepth.Enabled = true;
                txtHeight.Enabled = true;
            }
            else if (selectedMass == MassType.M_Cone.ToString().ToLower() ||
selectedMass == MassType.M_Cylinder.ToString().ToLower())
            {
                txtRadius.Enabled = true;
                txtHeight.Enabled = true;
            }



        }

        private void btnStart_Click(object sender, EventArgs e)
        {
            Operation = OperationEnum.ChangeAgent;
            Syncronized.ActiveSyncroniz = Syncronized.ActiveSyncroniz ^ true;
//XOR Wih 1!
            SetStartSetting();
            this.Close();
        }
    }
}
```

1- Developed code for conflict detection

```
#region Namespaces

using System;
using System.Text;
using System.Linq;
using System.Xml;
using System.Reflection;
using System.ComponentModel;
using System.Collections;
using System.Collections.Generic;
using System.Windows;
using System.Windows.Media.Imaging;
using System.Windows.Forms;
using System.IO;

using Autodesk.Revit.ApplicationServices;
using Autodesk.Revit.Attributes;

using Autodesk.Revit.DB;
using Autodesk.Revit.DB.Events;
using Autodesk.Revit.DB.Architecture;
using Autodesk.Revit.DB.Structure;
using Autodesk.Revit.DB.Mechanical;
using Autodesk.Revit.DB.Electrical;
using Autodesk.Revit.DB.Plumbing;

using Autodesk.Revit.UI;
using Autodesk.Revit.UI.Selection;
using Autodesk.Revit.UI.Events;

//using Autodesk.Revit.Collections;
using Autodesk.Revit.Exceptions;
using Autodesk.Revit.Utility;

using RvtApplication = Autodesk.Revit.ApplicationServices.Application;
using RvtDocument = Autodesk.Revit.DB.Document;

#endregion

namespace Salar
{
    [Transaction(TransactionMode.Manual)]
    [Regeneration(RegenerationOption.Manual)]
    public class ExtApp : IExternalApplication
    {
        #region Cached Variables
```

```
        public static UIControlledApplication _cachedUiCtrApp;

        #endregion

        #region IExternalApplication Members

        public Result OnStartup(UIControlledApplication uiApp)
        {
            _cachedUiCtrApp = uiApp;
            uiApp.Idling += AutoCall;
            try
            {
                RibbonPanel ribbonPanel = CreateRibbonPanel();

                //TODO: add you code below.


                return Result.Succeeded;
            }
            catch (Exception ex)
            {
                MessageBox.Show( ex.ToString() );
                return Result.Failed;
            }
        }

        public Result OnShutdown(UIControlledApplication uiApp)
        {
            try
            {
                //TODO: add you code below.


                return Result.Succeeded;
            }
            catch (Exception ex)
            {
                MessageBox.Show(ex.ToString());
                return Result.Failed;
            }
        }

        #endregion

        #region Local Methods

        private RibbonPanel CreateRibbonPanel()
        {
            try{_cachedUiCtrApp.CreateRibbonTab("NSS");}catch{}
            RibbonPanel panel = _cachedUiCtrApp.CreateRibbonPanel("NSS",
Guid.NewGuid().ToString());

            panel.Name = "NSS_Personal Modules_ExtApp";
            panel.Title = "Salar";

            ////Default button:
            PushButtonData pbDataExtCmd = new PushButtonData("ExtCmd", "ExtCmd",
Assembly.GetExecutingAssembly().Location, "Salar.ExtCmd");
```

```
            PushButton pbExtCmd = panel.AddItem(pbDataExtCmd) as PushButton;
            pbExtCmd.ToolTip = "ExtCmd";
            pbExtCmd.LargeImage =
BmpImageSource("Salar.Resources.ExtCmd32x32.bmp");
            pbExtCmd.Image = BmpImageSource("Salar.Resources.ExtCmd16x16.bmp");

            ////More buttons:


            return panel;
        }

        private System.Windows.Media.ImageSource BmpImageSource(string
embeddedPath)
        {
            Stream stream =
this.GetType().Assembly.GetManifestResourceStream(embeddedPath);
            var decoder = new
System.Windows.Media.Imaging.BmpBitmapDecoder(stream,
BitmapCreateOptions.PreservePixelFormat, BitmapCacheOption.Default);

            return decoder.Frames[0];
        }

        #endregion
    }
}
```